ERRATA

P. 167, line 20, 'trajectors' should be 'trajectories'.
P. 167, line 22, 'sight' should be 'site'.
P. 173, line 22, 'sight' should be 'right'.
P. 175, line 7, 'work' should be 'word'.
P. 178, line 9, $n = 100/20 = 5$, should be $n = 200/20 = 10$.
P. 182, line 30, G_2T, should be G_2T_2.
P. 204, line 3, abd should be adb.
P. 206, line 21, 4, 7, 9, should be .4, .7, .9.
P. 208, line 1, 200 should be 1200.
P. 215, line 18, 'sight' should be 'site'.
P. 226, line 6, 2 yds. should be .2 yds.
P. 234, line 4, should be $\frac{40+50+30}{3} = \frac{120}{3} = 40$.
P. 237, line 27, 'corrector' should be 'correction'.
P. 272, line 22, G_1T should be $G'T$. (Trajectory $G'T$ omitted from cut.)
P. 272, line 24, G_1 should be G'.
P. 273, line 10, G_1 T should be G' T.

GUNNERY

An Elementary Treatise

INCLUDING A GRAPHICAL EXPOSITION OF FIELD ARTILLERY FIRE

BY

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RESPECTFULLY DEDICATED

TO

BRIGADIER GENERAL WILLIAM WILSON SALE

Adjutant General, State of Virginia

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PREFACE

The author of this work, if it may be so styled, desires to explain its origin and its purpose.

With the idea of encouraging his officers to study, the Commanding Officer of the First Battalion Field Artillery, Virginia Volunteers, established a central school for the officers of the Battalion, the three batteries of which are stationed in Richmond, Norfolk, and Portsmouth, respectively. Instruction by correspondence was, therefore, necessary.

The first year's course, which extended from January to June, 1911, embraced Algebra, Drill Regulations, Fire Data, Hippology, Military Topography, Military Field Engineering, and 3-inch Material, suitable textbooks being obtained from the War Department. Upon the completion of this course of study, it was decided to continue the school for another year and to give particular attention to the subject of fire. It was thought that a knowledge of Ballistics and Explosives, however elementary, would be of great value to the student officers, but it was found that the available works on these subjects were too advanced for those who lacked a technical education. As Chief Instructor of the school, the writer then set about the preparation of a series of lectures, so elementary as to be within the grasp of all, and with the idea of explaining the reason why "for every rule." For the sake of convenience only, these lectures were united. A technical treatise was never contemplated, nor has a full and logical treatment of the subjects touched upon been attempted. These lectures are but a series of notes which it is hoped may assist in the study of the many

excellent textbooks to be had. Certain other information has been included which it was thought would prove of interest and benefit to the officers of the school.

That part of the introduction entitled "Study and the Value of Theory" was inserted at the very beginning of the book in the hope that the admonitions of the great soldiers therein set forth might arrest the attention and at once arouse the interest of officers inclined to look with impatience upon all forms of professional theory. It was thought that such officers would at least be inspired to exercise greater diligence in the study of the fundamental principles of their own branch of the service.

If the author has here and there entered upon the field of tactics, he must be pardoned, for it has only been done to emphasize technical points which tactical considerations frequently involve.

No claim to originality is asserted by the writer, except as to the arrangement of the book and the method of gradual development of the subjects treated, and the graphic solution of problems which in other forms appear unduly difficult to the novice. The text of the drill regulations has been closely followed in several instances at some length, because there was nothing in the particular passages requiring elaboration, and it was necessary to include them in order to preserve the continuity of the discussion. The writer has not hesitated to use verbatim the best he could find from the following sources, which should be consulted by the ambitious artillery student:

The Field Artillery Journal; The Infantry Journal; War Department Reports on Shrapnel Fire; Modern Guns and Gunnery, Bethell; Ballistics, Hamilton; Interior Ballistics, Ingalls; Ordnance and Gunnery, Lissak; Ordnance and Gunnery, Metcalf; Ordnance and Gunnery, Bigelow; Ordnance and Gunnery, Bruff; Military Explosives, Weaver; Artillery Circular B, 1902, Walke; Artillery Circular H, 1893, Bliss;

Gunnery and Explosives, Westervelt; Handbook for Light Artillery, Dyer; Handbook for 3-inch Material; Artillery Drill Regulations; Field Service Regulations; Weldon Range Finder, Pamphlet, War Department; Applied Principles of Field Fortifications, Woodruff; Military Field Engineering, Beach; Notes on Field Artillery, Spaulding; Field Artillery with the Other Arms, May; The Tactical Handling of Q. F. Field Artillery, Roquerol; Selected Translations Pertaining to Boer War, War Dept.; German Official Account of the War in South Africa; U. S. Official Reports of the Boer War; U. S. Official Reports of the Russo-Japanese War; A Staff Officer's Scrap Book, Hamilton; Military Memoirs of a Confederate, Alexander; The Science of War, Henderson; Various Accounts of the Franco-Prussian War.

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INTRODUCTION

STUDY AND THE VALUE OF THEORY

"Success in war is almost wholly in the hands of the officers. There have been soldiers' battles, in which the valor of the man has redeemed the blunders of the general, but, as has been truly observed, there has never been a soldiers' campaign. Even the most enthusiastic patriots must be led; and an army of stags, says the adage, commanded by a lion, is better than an army of lions commanded by a stag." Thus has Henderson truly written.

In consequence of this truism, on every hand we hear the young officer, especially the volunteer, despairingly inquire how may he prepare to honorably acquit himself of the obligations which war will impose upon him. He is appalled by the increasing demands of the military profession and, in proportion to his earnestness, alarmed by an appreciation of his own ignorance. "I desire to do all in my power," says he, "but know not what to do to prove a lion rather than a stag should the rôle of a leader become my part."

While the following argument is adapted to the artillery officer, it being presupposed that this paper will find readers in that branch of the service upon which the greatest demand is now being made by reason of the radical developments in the science of gunnery, yet the appeal is general. It is believed, however, that in no other branch of the service will the value of theory be more easily perceived than in the artillery.

To Wellington is attributed that oft-repeated remark:

"Waterloo was won on the playgrounds of Rugby." I seriously doubt if such a remark were ever made by one, who, like Wolfe, was one of the most zealous students of his time, any more than Lee ever claimed the superiority of the Army of Northern Virginia over its antagonists during the first years of the war to have been due to the thoroughbred horse and the shooting dog of the South. Both Wellington and Lee recalled too often the hours they had devoted to professional study; both too frequently witnessed the blunders of gallant but ignorant men, to attribute victory to courage and physical training alone.

The repetition of this supposed saying, unqualified as it is, of so great a soldier as Wellington, has perhaps done more harm than good, for thereby the thoughtless are only confirmed in the belief that great generals are lurking upon every playground and will emerge from obscurity in the hour of need. Thus is the world misled, and in the pursuit of such a phantasy does our own country lead. The fact that untutored soldiers have met with miraculous successes renders impatient the average citizen with all but the unprofessional. If only the brilliant aphorisms of General "Dick" Taylor could strike the popular conscience with full force innumerable disasters would be averted. The very title of his book, itself a most valuable contribution to unprejudiced history, is suggestive of our military policy—"Destruction and Reconstruction." But I cannot refrain from quoting a passage therefrom which contains in a few words what nations have failed to grasp through centuries of experience.

"Although since the days of Nimrod war has been the constant occupation of men, the fingers of one hand suffice to number the great commanders. The 'unlearned' hardly think of usurping Tyndall's place in the lecture room, or of taking his cuneiform bricks from Rawlinson, yet the world has been much more prolific of learned scientists and philologers than of able generals. Notwithstanding, the average

American . . . would not have hesitated to supersede Napoleon at Austerlitz or Nelson at Trafalgar. True, Cleon captured the Spartan garrison, and Narses gained victories, and Bunyan wrote the 'Pilgrim's Progress,' but pestilent demagogues and mutilated guardians of Eastern zenanas have not always been successful in war, nor the great and useful profession of tinkers written allegory."

It may be added that, while all thoroughbreds do not make race horses, yet we are not justified thereby in entering percherons in a great event.

The fact, however, that the lessons of the great conflict of 1861–5 will be forgotten before the advent of another war, and that the professional soldier will be discredited at first to the great loss of a people misled by conceit, does not relieve him from the obligations of his calling. Nor do I mean to suggest that the professional is necessarily educated and worthy of high command. The mere fact that he has bloomed forth from a cadet to a subaltern of the line does not imply that he will imbibe the principles which constitute the science of war and develop the qualities of a leader. Until recently it would seem our youthful soldiers were expected to absorb military experience from the air of the Hudson. While the course of mathematics and physical training through which they passed was most excellent, it was preposterous to suppose that the youth could acquire along with a technical education any more than a foundation of ability for future command. How ludicrous must have appeared the mere graduate of our Academy to the highly cultured officers of the foreign staff colleges! But with our general staff has come a conception that West Point alone cannot make generals, however valuable its system may be in weeding out unsuitable material.

Rüchel said the soul of the Prussian Army was in its officers. That the spirit of the corps of officers bespeaks the spirit of the whole army is claimed by Von der Goltz to be

but a repetition of what is universally observed in political life. " So long," says he, "as the educated, the leading, classes maintain their efficiency, the people also will be stout and capable." And again he asserts that especial value must be laid upon education, because it is the basis of noble and moral qualities.

Frederick, Napoleon, Clausewitz, Von der Goltz, Wolseley, and many others have attempted to analyze the composition of a great general, education in each estimate being cited as an important element, and though Timur and Onosander did not use the word, the requisite attributes enumerated by them can only spring from the loin of knowledge. Lord Roberts reminds us that even self-reliance, that cardinal requisite of a successful general, can only come from the most careful education. Therefore, it would seem it is not to be expected that men devoid of military knowledge and experience, however courageous and patriotic they may be, will develop into successful leaders on the battle field.

The tendency, or perhaps I should say the habit, of the uneducated soldier, as well as of the citizen, has ever been to minimize the importance of theoretical work. It is too common that we hear him scoff at "paper war." He prefers to lay aside the pen while the blade rusts idle in the scabbard. But it has been my observation that such indifference is due more to ignorance than to conviction, and that with the dawning of the military light the true value of theory is seen.

This is true. A man could not make an intelligent survey in the field unless he had been trained in the theory of his instruments. Neither can the officer who has never had the experience of actual campaign hope to acquire a practical knowledge by groping in the dark. There is no place for the military empiric to-day. Indeed, the lessons of actual warfare are not digestible to those who lack the saliva of theory—they are negative rather than positive.

"In all ages the power of intellect has asserted itself in war. It was not courage and experience only that made Hannibal, Alexander, and Cæsar the greatest names of antiquity. Napoleon, Wellington, and the Archduke Charles were certainly the best educated soldiers of their time; while Lee, Jackson, and Sherman probably knew more of war before they made it than anyone else in the United States." The fact that the training of some successful leaders, for instance, Cromwell, Marlborough, Clive, Nelson, Grant, and Forrest, was altogether practical is but the exception proving the rule that most great soldiers are deep students of war.

Frederick the Great, in speaking of officers who relied on their practical experience alone, caustically remarked that there were in the army two commissariat mules which had served through twenty campaigns, "but," he added significantly, "they are mules still."

Von der Goltz states that illustrious soldiers always become more clear-sighted and resourceful in moments of the greatest danger, while around them all are working with blunted senses. He then goes on to discuss courage, *a divine courage*, as that which clears the mind at such a time. But to what end would the mind be taxed if the mental armory were not well stored with military resources? The dispatches of Napoleon, of Wellington, and of Moltke are sufficient proof that they depended upon hard thinking and calculations, rather than upon a God-given courage or upon the principle of *stat pro ratione voluntas* which we are so fond of associating with genius.

"If I were asked to put my finger on the most important lesson that may be learned from the past, I should reply," says Henderson, "that history teaches us that courage, numbers, armament, and entrenchments are of no avail if the troops are badly led. . . . "

Some men, in fact a majority of men, are by nature so con-

stituted as to render them unsuited to command. Such men, while they will not be developed into leaders by study, will be greatly improved.

Theory, applied to the profession of arms, is to some an obnoxious word, but only to those who disdain the advice of Napoleon. "It is not pretended" says McDougall, "that study will make a dull man brilliant, nor confer resolution and rapid decision on one who is timid and irresolute by nature, but the quick, the resolute, the daring, deciding and acting rapidly, as is their nature, will be all the more likely to decide and act correctly in proportion as they have studied the art they are called upon to practice."

One who studies the life of the hero of St. Vincent, the Nile, Copenhagen, and Trafalgar, must be impressed by Nelson's utter lack of grasp of the fundamental principles of strategy in the earlier years of his career. In discussing the Admiral's erroneous views as to Napoleon's impending Italian campaign, Mahan, in his epochal work, says:

"The mistake, if mistake it was, illustrates aptly the errors into which a man of great genius for war, of quick insight, such as Nelson indisputably had, can fall, from want of antecedent study, of familiarity with those leading principles, deduced from the experience of the past, which are perhaps even more serviceable in warning against error than in prompting to right."

Who shall say that Nelson's early career would not have been even more illustrious had he been a deep student of war?

"Without character and capacity, physical and moral courage, coolness, and self-reliance, it is impossible," says Henderson, "that a man can become a great soldier." "But," he adds, "however strong he may be in the possession of such qualities, study and practice can never be anything else but beneficial."

One of our most distinguished Confederate generals, referring to officers not exceptionally gifted, said: "Conscientious

study will not perhaps make them great, but it will make them respectable; and when responsibility of command comes they will not disgrace their flag, injure their cause, nor murder their men."

Military science, the study of which is so earnestly advocated by all great soldiers, is in no sense an arbitrary code. On the contrary, its principles are the essence of an experience which the student but acquires second hand. The maxims of Napoleon are but deductions from a practice of which he was the most successful exponent. The genius of Bonaparte amplified rather than blindly followed hitherto existing rules of war.

The benefit to be derived from the study of the military art is the mastery of a theory upon which the soldier may act with some degree of confidence. As new weapons are evolved or old ones developed, it becomes necessary to postulate a theory for their use, which it may not always be possible to base upon actual experience. In such case the theory is but a mental picture gained from the study of a map. The traveler may find practical obstructions in his way, but the short-cuts will enable him to regain his course, whereas one insensible of the general direction is only confused by the by-paths which might have subserved his convenience. Which of the by-paths we find in practice are to be followed can only be known by keeping in mind our general trend. Followed blindly, as practical obstacles arise, these routes will only serve to lead us astray. There is no time in actual campaign to explore each alley of the maze—*tentanda via est.* And so it is certain that he who experiences the failure of a theory is more able to rectify his course than one who encounters difficulties without being able to discern the false turns in the road.

It is true that theory by itself will avail but little. When he was asked the best means of learning the art of war, Lord Seaton, a Peninsular veteran, replied: "Fighting, and a d—d

deal of it." But practical experience falls to the lot of few, and unless it forms a basis for reflection, and is amplified by comparison with the experience of others, loses half its value. Reflection and comparison are obviously impossible unless the brain has been trained to think, and the mind is stored with knowledge of the past.

The Archduke Charles remarked that much experience and a passion for study were indispensable requisites to form a great captain. "What we have seen with our own eyes," says he, "is not sufficient, for where is he whose life has been so eventful as to have made him experienced in everything? He can only become an able general who adds the knowledge of others to his own; who appreciates the researches of those who have gone before him; and who recurs to the military exploits and great achievements which the history of war supplies, as his standard of comparison."

Thus we see that this illustrious soldier, while asserting the necessity of practical experience, insists upon study as a pre-requisite to leadership. We must not be misled by an erroneous construction of Napoleon's maxim, which says: "Commanders-in-chief are to be guided by their own experience or genius. Tactics, evolutions, the science of the engineer and the artillery officer may be learned from treatises, but generalship is acquired only by experience, and the study of the campaigns of all great captains." There is no warrant to underestimate the weight accorded the element of study by the author of this saying. The language of Napoleon and the Archduke alike enjoins us to consider practice and theory in conjunction, Lord Seaton notwithstanding.

It is not intended to disregard that essential quality of military genius which, so far, has never been defined; that quality which Jackson of the Valley possessed and which Jackson of the Peninsula lacked—that indefinable quality which made Jackson the hero of the Shenandoah, and Hood the failure of Spring Hill. No conception of Jackson's mind

could have been more masterly than Hood's execution up to the moment for attack at Spring Hill. Had his orders even then been obeyed the Confederacy would have claimed another genius, and the bloody disasters of the Harpeth would not be recorded in history. My point is that the plan is but the theory—without more the conception is valueless—and it is that illusive something bridging over with a hair the chasm between victory and failure which Jacksons possess and Hoods lack. In the distinction the question of courage plays no part. Von der Goltz has only in part predicated the truth, for surely Hood was not braver at Franklin than the day before, nor was Jackson of Bull Run lacking in courage while on the Chickahominy. The psychological element of military success on the battlefield cannot be further discussed here. It is merely alluded to in order that the writer's argument in favor of another element may not be said to ignore psychology in war.

That theory may be preconceived as well as retrospective in character is also true. The most striking example of the application of such a theory is that presented by the French mind and pen. Without firing a shot the logicians of France have forced upon a reluctant world, somewhat contemptuous after Sedan, the recognition of the fact that the philosophy of war is not necessarily forged in the white heat of battle. Without firing a shot the French army has been rehabilitated, and little has been borrowed from its erstwhile conqueror except the conception of military brain power, of which Moltke, at the head of the German Great General Staff, was an illustrious exponent.

Less than twenty years ago, not only the present type of field gun, but the method of its employment, was deduced by General Langlois of the French Army. Looked upon at the time (1892) as chimerical, the theories of this celebrated artillerist took form about 1898. Germany, at first inclined

to make light of the whole plan, was soon won over, and to-day the rapid-fire gun, which at first appeared utterly impractical, awaits a chance to demonstrate its power in the hands of the modern artillerist. I say awaits its chance advisedly, for, contrary to the general belief, this gun has not yet been tried in war, if we believe Brigadier-General M. M. Macomb, U. S. Army, who was present in the capacity of a military observer at all the great battles of the Russo-Japanese War and clearly distinguishes the field guns used by both armies from our own type and those of most of the European powers.

But in spite of the French Revolution in the science of field artillery one salient feature remains the same as before—the final test of artillery efficiency, the ultimate object of the artillery, is to deliver an effective and timely fire, for this is the only arm that has no action except fire. To this extent then the French theory is not preconceived.

The experiences which field artillery will undergo in actual campaign are summed up by General Macomb as follows:—

1.—Transportation.
2.—Camping.
3.—Marching.
4.—Bivouacking.
5.—Occupation of position.
6.—Fire.

And the greatest of all these is fire. No amount of tactical knowledge on the part of the officers, no excellence in marching, camping, scouting, reconnoitering, etc., no perfection in artillery duties up to the time of opening fire, is of any use whatever, if the battery cannot hit; in such case artillery becomes "*telum imbelle, sine ictu.*"

Fire then is the ultimate end of field artillery; it is the only reason for its existence; if ineffective in fire, it has no title to respect.

"There is a school of writers who claim that the efficiency of modern weapons is but little greater than that of the older

ones, due to the fact that every weapon must be operated by a man, and that men, as fighters, have deteriorated with the progress of civilization, in almost the same degree that weapons have improved—that, under the best of circumstances, men get as much excited, and just as much demoralized, as ever; that these emotions manifest themselves in dimness of eyesight, trembling of the hands, oblivion to surroundings, neglect of details, etc., etc." There may be a good deal of truth in this. The greater the extent to which it is true the greater the necessity for every man in the artillery, the weapon of which is the most intricate of all, to become so accustomed to the performance of his duties that he will do his part as a matter of habit. The effectiveness of our fire depends upon the turn of numberless cranks. However accurate all others may be, if one single man neglects his turn the shot goes wild. And who of us wishes to fail at the critical moment so long expected and so long and earnestly prepared for at the expense of millions of treasure? Think of the mortification which would come to us should we encounter the reproachful gaze of a gallant and shattered infantry! Failure in peace is a bitter portion—failure in war is worse by the number of lives it costs. And so the artillerist must study; he must familiarize himself with every turn of the crank, so that failure, if it must come, will be due to the crank and not to the negligent ignorance of the operator.

Every nation has either evolved a doctrine of war or adopted the conception of another. Whether it be French or German in spirit, adhered to by the British and the Japanese respectively, its doctrine is that which gives to an army the energy of definite motion. Without a conception of war the bravest army is inert and, like that of Kuropatkin, its striking power is worn away in useless friction.

The spirit of the doctrine must permeate every unit——nay more—every breast, and that of the Field Artillery must be:

Co-ordination of men, horses, and material by industry and care;

Attention to detail, unselfish co-operation, unswerving obedience without fear of responsibility;

Strong initative, careful consideration, prompt decision, and celerity of execution. From these an effective fire will result.

Just as there is a tendency on the part of the ignorant to decry theory, so there is danger of the military bookworm becoming fettered by formulæ. This extremity is, of course, as pernicious as the other. "I hope," says Lord Wolseley, "the officers of her Majesty's Army may never degenerate into bookworms. . . . At the same time, all now recognize that the officer who has not studied war as an applied science; who is ignorant of modern military history, is of little use beyond the rank of Captain. . . . Experience enables me to warn all these determined men of how small their chance is of ever reaching any great position in the army unless they devote many of their spare hours every week to a close study of tactics and strategy as dealt with in the best books upon recent wars."

It is a mistake, I believe, for the student, even though he be a citizen soldier, to conclude that the practical science of field artillery, at least, has become so thoroughly formulated as to leave no room for the brilliant originality of what we call military genius. The zest with which the good volunteer officer undertakes his duty is in itself sufficient to ensure the rapid mastery of his duties and an efficiency which will equal, and possibly at times excel, that of the professional grown old in the service, for the stranger often detects that in our midst which we ourselves have not seen. With work which is a half-pastime, wherein they find relief from the routine of their ordinary avocations, monotony has no place. The very freshness of their obligations is attractive of zeal and industry.

With each advance in the art of war, somebody must practically demonstrate the proper usage under the innovation; here comes into play the mental enthusiasm of the volunteer which gave to Europe a new system of artillery tactics in 1861–5, along with many other developments in the art of war. The writer is happy in the feeling that the unbending tenacity of Pendleton, of Long, of Lindsay Walker, of Carter, of Poague and the brilliant initiative of Alexander, of Pegram, of Pelham, of Haskell, of Latimer, of Dearing, and of Chew, which together constituted a creative force, will prove of even more practical value in the application of modern tactics than in the past. Why should this not be so? The modern weapon is of such infinite superiority to that of the 60's that the impress of genius must be the more keenly felt. We must not rely upon genius, however, but upon the man-made rather than the God-given leader.

At the close of this somewhat random dissertation on the value and the necessity of theory, let me, therefore, recommend the advice which Sir Charles Napier, a military genius himself, who did not disdain to study his profession, but thought it indispensable to success, gave a young officer:

"By reading you will be distinguished; without it, abilities are of little use. A man cannot learn his profession without constant study to prepare especially for the higher ranks. When in a post of responsibility he has no time to read; and if he comes to such a post with an empty skull it is then too late to fill it. Thus many people fail to distinguish themselves, and say they are unfortunate, which is untrue; their own previous idleness unfitted them to profit by fortune."

And if there still remain any doubt in the young officer's mind as to the way to fit himself for command, let him ponder the encouraging advice of the greatest genuis war has produced. Said Napoleon: "Read over and over again the campaigns of Alexander, Hannibal, Cæsar, Gustavus, Turenne, Eugene, and Frederick. Make them your models. This is the only

way to become a great general, and to master the secrets of the art of war. Your genius, when enlightened by this study, will induce you to reject such maxims as conflict with the principles of those great commanders."

The lesson which it has been attempted to impress upon the mind of the young officer in the foregoing pages is, whether he be lieutenant or of higher degree, let him not rust his mental faculties, for in peace the textbook and the pen must serve as the military lubricant. But study to be of benefit must be systematic, and further, it must not be mere drudgery. Without system, the labor of study multiplies itself and dulls our interest. The most zealous student must feel that his efforts are being rewarded, and for this reason intellectual culture must be accompanied by mental enjoyment. The writer, therefore, makes bold to supplement the advice of the great leaders which he has embodied herein by appending a course of military study, elementary, yet progressive, for the repetition of such advice without guidance is more or less superficial.

It is not pretended that the authorities cited are the best from every viewpoint, yet it is asserted with some degree of confidence, based upon an intimate acquaintance therewith, that few dull pages will be encountered in the prosecution of the proffered course. It is to be observed that where possible a work containing a general view is included as the framework about which to group those of less general, though perhaps of more interesting, character.

The list is comprised of about eighty works, the total cost of which would not exceed $300.00. Thus, it is within the power of any group of battalion or regimental officers to acquire such a library in a short time without overtaxing the individual, affording to the whole a course of reading which could extend over a period of from five to ten years with advantage, the more zealous students devoting their attention to technical treatises on strategy and tactics along with the works enumerated.

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	3.—The Crisis of the Confederacy: Battine.
	4.—Military Memoirs of a Confederate: Alexander.
	5.—Battle of Chancellorsville: Hamlin.
	6.—Battle of the Wilderness: Schaaf.
	7.—Studies Military and Diplomatic: Adams.
	8.—Battles and Leaders of the Civil War.
	9.—Science of War (Portions pertaining to Civil War): Henderson.
	(Consult "Rebellion Records.")
Seven Weeks' War (Austro-Prussian). 1866.	1.—The Seven Weeks' War: Hozier.
	2.—Campaign of Königgrätz: Wagner.
Franco-German War 1870–1.	1.—With Royal Headquarters, 1870–71: Verdy du Vernois.
	2.—My Experiences of the War between France and Germany: Forbes.
	3.—The Battle of Spicheren: Henderson.
	4.—Franco-German War: Moltke.
	(Consult German Official Account.)
Russo-Turkish War. 1877–8.	1.—Russo-Turkish War: Hozier.
	2.—Russian Army and its Campaigns in Turkey, 1877–8: Greene.
	3.—Operations of Gen. Gurko's Advance Guard, 1877: Epauchin.
	4.—Tactical Studies on the Battles around Plevna: Von Trotha.
	5.—Experiences of a Prussian Officer during Russo-Turkish War: Von Pfeil.
Egyptian Wars. 1881–1898.	1.—General Gordon: Butler.
	2.—With Kitchener to Khartoum: Steevens.
	3.—With Fire and Sword in the Sudan: Slatin Pasha.
	4.—Recollections of a Military Life: Adye.

China-Japan War.. 1894.	1.—Japan-China War: Inouye. 2.—China-Japan War: Vladimir.
Græco-Turkish War. 1897.	Græco-Turkish War: by a German Staff Officer.
Spanish-American War. 1898..	1.—Report of Santiago Campaign: Wagner. 2.—Santiago Campaign: Wheeler. 3.—The War with Spain: Lodge.
South African War. 1899–1901.	1.—Operations in South Africa: U. S. War Dept. Reports. 2.—My Experiences of the Boer War: Count Sternberg. 3.—The War in South Africa: Mahan. 4.—The Second Boer War, 1899–1900: Wisser. 5.—German Official Account, Paardeburg to Pretoria: DuCane. (Trans.) 6.—Three Years' War: De Wet.
Philippine War and Chinese Relief Expedition. 1898–1900............	1.—Memories of Two Wars: Funston. 2.—America in Chinese Relief Expedition: Daggett. 3.—Operations in China: U. S. War Dept. Reports.
Russo-Japanese War. 1903–5.	1.—A Staff Officer's Scrap Book: Hamilton. 2.—From the Yalu to Port Arthur: Wood. 3.—The Truth about the War: Taburno. 4.—History of War in Manchuria: London *Times*. 5.—U. S. War. Dept. Reports. 6.—With Kuroki in Manchuria: Steevens.

CLASSIFICATION OF FIELD ARTILLERY

There seems to be more or less confusion with respect to the classification of Field Artillery. The following will, therefore, prove instructive.

Most of the difficulty seems to come from a confusion of the terms "siege artillery" and "heavy field artillery," which are taken to be synonymous, while in reality they are not. A large part of this confusion arises from a failure to know or to recognize the fact that heavy field artillery is a product of almost the last decade only, while siege artillery is a very old designation and has now largely lost its significance.

In separating the field artillery from the coast artillery in 1907, Congress decreed that "the field artillery is the artillery which accompanies an army in the field, and includes light artillery, horse artillery, siege artillery, and mountain artillery," thus uniting under one caption all the varieties of mobile artillery at that time in our service. This definition, therefore, also indicates the scope of the duties of the field artillery.

It should be noted that the significance of the word "field" is here considerably extended, and is made general instead of referring to a special class of artillery. When "field artillery" is spoken of abroad, that artillery armed with the 3-in. or 75-mm. gun is meant; in other words, it is a specific class, whereas with us the term is a general one, including a number of varieties.

Mountain Artillery.—The name indicates the use. This artillery, primarily intended for rough country impracticable for wheels, is packed on animals. The gun is light, weighing about one-third as much as the standard light-battery gun,

but firing a projectile of about the same size. From these two conditions it necessarily follows that the range is short, not over one-half that of the light-artillery gun. While, as stated, normally the battery is transported by pack transportation, in many countries shafts are also provided in order that the animals may be relieved when practicable by utilizing draft. This is, of course, easier on the animals, but many officers in our service do not believe in having any draft for two reasons: First, when using packs the shafts, which must also be packed, catch on trees, vines, etc., and interfere with movements; and, second, if it is feasible to use draft or wheeled transportation, light artillery should be substituted for mountain. Our mountain artillery is at present equipped with the 2.95-in. Maxim-Nordenfeldt gun, but this weapon will be replaced by a 3-in. mountain howitzer firing a 15-lb. projectile. In this class of artillery the weight should not exceed about 300 lbs. for each pack animal.

Light Artillery.—This designation, which is one of long standing in our service, corresponds to the special designation, "field artillery," in use abroad. In all countries this artillery is very similar, the projectile weighing about 15 lbs., and the range being about 7,000 yards. But in speaking of the range, it must be borne in mind what is most needed in war is not extreme range, but the most effective range, and that the effect of shrapnel falls off quite perceptibly beyond 3,000 yards. Beyond this range the guns shoot almost as accurately as below it, but many things combine to make long-range firing more or less ineffective. With the field gun, as the range increases more and more ammunition is necessary to produce the desired effect. This is due to the great angle of fall and also to the small remaining velocity making the shrapnel more and more local in its effect, while at the same time the difficulty of observing and adjusting the fire increases with the range, and accurate observation is essential to prevent waste of ammunition. In our

service, light artillery is armed with the 3-in. rapid-fire gun, throwing a 15-lb. projectile and having a weight of about 4,200 lbs. behind teams of six horses.

Horse Artillery.—Horse artillery is primarily designed to accompany cavalry. All the personnel are mounted on horses. It is readily seen that, if the guns are to keep up with the cavalry, every effort must be made to lighten the weight behind the teams, and hence the cannoneers, instead of riding on the carriages, are provided with saddle-horses. In time of peace the casual observer sees little difference between light and horse artillery, but every war brings out the distinction clearly. When the ammunition chests are full, the forage scant, the roads bad, and the work continuous, the difference in mobility between these two classes of artillery is at once apparent. Horse artillery is, therefore, designed not only to accompany the cavalry, but also to reinforce parts of the battlefield as quickly as possible. The Franco-German war shows many cases where the horse artillery, due to its greater mobility, arrived at critical times several hours ahead of the light or field artillery, and in the recent war in the far East the lack of horse artillery on the Japanese side prevented them from ever converting a Russian retreat into a rout. In some countries the horse artillery is provided with a lighter gun and carriage than has the light artillery, and the gun fires a projectile weighing slightly less. In our service the horse artillery has the same gun as has the light artillery, thus avoiding the complication in ammunition supply which would be caused by the introduction of another caliber. Whether, however, the gun is sufficiently mobile is a question that has not yet been determined. The English have the latest-adopted horse-artillery gun, which fires a 12½-lb. projectile. They seem to be very much pleased with their horse-artillery gun. One solution that has been suggested in our service is to use the present gun and carriage but to carry less ammunition, thus reducing the weight behind the teams.

The experience of all wars has shown that the work of horse artillery is arduous, and that upon returning from any expedition the horses are badly in need of rest. In our service it is, therefore, wisely provided that the harness and the saddle horses shall be interchangeable, thus providing some relief for the draft horses. Those authorities who advocate a special gun for the horse artillery limit the weight to about 3,400 lbs. behind a six-horse team.

Heavy Field Artillery.—This is the most recent development of field artillery, and consequently the character of the material and the use to which it will be put are not as clearly worked out as with other classes of artillery. The tendency of troops, both on the offensive and defensive, to take cover has steadily increased with the improvement in guns and small arms, with the result that in the contest between light guns and cover the latter reached a point where the former was overmatched. Theoretically, the advantage should always be on the side of cover, for there is no limit to the amount of digging that could be done, while there is clearly a limit to the weight of gun; but, practically, the question of time to construct the cover enters, as well as the fact that if the position is too strong to be attacked troops will be maneuvered out of it. However, it is recognized that the works thrown up in a day or two are beyond the power of the light field gun, and hence the heavy field gun becomes necessary. Such artillery is a part of every army, and foreign regulations state that its presence may be expected on every battlefield in the future. The gun is as heavy as is consistent with giving it the mobility of infantry in masses. The confusion in our service, due to the loose use of the term "siege artillery," is caused by failure to recognize that the heavy field artillery accompanies the army at all times and is used on practically every battlefield. It takes up the work where the light gun leaves off. The heavy field gun in our service

TABLE OF FIELD GUNS, 1910.

	America, 1902	Argentina 1908	Austria, 1905	Belgium, 1905	Brazil, 1904	Bulgaria, 1905	Denmark, 1902	England, F. A., 1903	England, H. A., 1903.	France, 1898.	Germany, 1906.	Greece, 1907	Holland, 1903	Italy, 1906	Japan, 1905.	Mexico, 1902.	Norway, 1900.	Portugal, 1904	Roumania, 1904	Russia, 1903.	Servia, 1907	Spain, 1906.	Sweden, 1902	Switzerland, 1903	Turkey, 1904.
Caliber, inches	3	2 95	3 01	2 95	2 95	2 95	2 95	3 3	3	2 95	3 03	2 95	2 95	29 5	2 95	2 95	2 95	2 95	2 95	3	2 95	2.95	2 95	2 95	2 95
Weight of shrapnel, pounds	15	13 2	14 72	14 3	12 1	14.3	11 85	18 48	12 54	15 96	15	11 3	13 2	14 3	14 3	13 61	14.3	14 3	11 3	14 41*	14 3	14 3	11 3	11	11
Number of bullets	252	295*	316+16	360	235	294	295	364	263	300	300	305	270	360	210	250	280	201	295	260	305	291	295	210	295
Number to the pound	36 5	50*	50 & 35	50	42	45	41 3	42	42	38	45	45	41 3	50	36 4	38	42	43	42	43	45	45	42	36.3	45
Whether H. E. shell carried	Yes	Yes.	Yes.	Yes.	Yes.	Yes.	No	No	No.	Yes	Yes	Yes	Yes.	Yes.	Yes	No.	No	Yes	Yes	Yes.	Yes	Yes.	No	Yes	Yes
Muzzle velocity, fs.	1700	1065	1640	1640	1600	1640	1610	1590	1658	1739	1525	1610	1610	1675	1700	1610	1610	1610	1640	1930	1640	1610	1640	1590	1590
Muzzle energy, foot tons.	300	254	275	266	215	266	277	324	239	334	242	267	245	270	288	255	267	267	367	373	267	267	267	245	241
Nature of powder.	G C	N. G.*	N.G.	G C	N G	G C	G C	Cor	Cor.	G.C	G.C	G C	G C	N G.	Cor.	G C	N.G	G C	N.G	G C	G C	G C	G C	G C	G C
Weight of gun, cwt.	6 9	6 5*	7	6 67	5 7	7.52	6 42	9	6	9	7 66	6 7	6 9	6 9	6 8*	6 5	6 5	6 67	7 37	7 85	6.6	6 67	6.7	6 48	6 85
Weight of gun and carriage, cwt.	21	18	20	20	16.3	20 25	20.5	21 75	19 5	22 4	18 6	21 3	19.5	19 75	19.7	20 8	19 75	21.25	21	20 75	20 4	20 4	19.15	19 75	19 4
Weight of gun and limber filled, cwt.	37 3	31 5	37.5	34 5	26.7	34.5	36.6	40	32 75	37	34 4	35.5	34 7	33 45	33.25	36 3	36	35.5	34 8	38 5	35	34 2	35.3	35.5	35 5
Springs or compressed air	S	S.	S.	S.	S	S.	S.	S	S	A.	S	A	S	S	S.	S	S.	A	S	S.	A	A	S	S	S
Maximum elevation, degrees ..	16	15*	18	15	17	15	15	16	17	17	16	16	16	17	17*	17½	15½	16	16	16¾	16	16	16	16	152
Traverse each way, degrees	4	3	4	32	3	3	3½	3	3	3	4	3	3½	3½	3	2½	3½	3	32	2¾	3	3	32	2	3
Length of recoil, inches	50	48	51.5	51	44	50	54	48	48	43	44	50	47	57	55	44	48	50	54	42 5	50	50	51	53	48
Height of wheels.	4' 8"	4' 32'	4' 3"	4' 3¾"	4' 2"	4' 4"	4' 3"	4' 8"	4' 8"	4*	4' 5½"	4' 1"	4' 3½"	4' 3½"	4'3½"*	4' 3½"	4' 3½"	4' 4"	4' 3½"	4' 4"	4' 4"	4' 3½"	4' 3½"	4' 3½"	4' 3½"
Track of wheel, inches	62	58	60	58	58	57	59	62	62	55	60	61	58	58	55	60	55	61	58	60	61	61	58	55	58
Line of sight, whether independent	No	Yes.	No.	Yes	No	No	No.	Yes.	Yes.	Yes	No.	Yes.	No.	Yes.	No.	Yes	No.	Yes.	No	No.	Yes.	Yes.	Yes.	No	No
Sights—Goniometric, Telescopic, Panorama or Ordinary.	O.P	T G.	P.	P	T G	O	T.G	T.G.	T G	G.	T G	G	T G	T.P	T G.	G P	O.	G	T.G.	O P.	O.P.	T G.	T G.	O.	O.
Material of gun..	N S.	N S	B	N S.	N.S	C S	N S	S	S	N S.	N S.	S.	N S.	N S	S	S.	N S	C.S	N S	S	S.	C S	N S	N S	N.S
Length of gun, calibers	29 2	30	30	30	28	31.4	30	29 4	24.4	36	27.3	31 5	30	30	30	30	31	31 4	30	30	30	30	30	30	30
" " " inches	87.6	88	90 3	88 5	83	92 5	88.5	97	73 25	106	83	93	88 5	88.5	88 5	88.5	91.5	92 8	88 5	90	88.5	88.5	88 5	88 5	87 75
Breech action—wedge, swinging block, or eccentric screw	S B	W	W	W	W.	S B.	W	S.B.	S B.	E S	W	S.B.	W	W	W	E S	E S	S B	W	S B.	S.B.	S.B.	W	W	W
Thickness of shield, millimeters	5	4	4 5	5	4½	4	6	?	?	5	4	4	4	4	3 6	5	4	5	1	5	4.25	4.25	4 75	4.75	4
Traverse on pivot or axle	P	P	P.	P	P.	A	P	P	P.	A	P	A.	P.	P	P	P.	P	A	P	A	A	A.	P	P	P
Rounds in limber	36	32	33	40	32	38	44	24	24	24	36	38	40	32	36	36	36	38	24	36	38	38	44	40	44
Rounds in wagon limber	36	32	30	40	40	38	48	28	28	24	36	38	40	32	36	36	36	38	24	40	38	38	48	48	44
Rounds on wagon body	70	56	60	64	40	60	72	48	48	72	52	60	64	64	60	64	64	72	64	48	60	60	48	48	52
Rounds per gun.	358	296	168	242	192	250	284	176	176	312	126	332	196	224	228	236	236	258	288	212	234	278	284	280	188
Weight of wagon, packed, cwt.	37	30.6	38.5	35 3	24	34	39 4	36 75	30 5	38 5	35	33	36 35	36	34 5*	36 5	40.5	37.4	34	38	32	32	36.3	35 3	36.25
Percentage of H. E. shell. .	?	?	33	?	?	?	Nil.	Nil.	Nil	11 5	20 2	?	17.3	?	33	Nil	Nil	?	29 5	?	?	20	Nil.	?	?
Number of guns in battery..	4	6	6	4	4	4	4	6	6	4	6	4	6	6	6	4	6	4	4	8	4	4	4	4	6
Number of wagons in battery.	12	18	9	8	8	9	8	12	12	12	6	12	9	12	12	8	12	8	12	16	10	10	10	10	9
Maker..	State and Ehrhardt.	Krupp.	State, Skoda, and Ehrhardt.	Krupp and Cockerill	Krupp.	Schneider	Krupp.	State, E. O. C., V. M. and C. O. W.		State	State	Schneider.	Krupp.	Krupp.	State.	St. Chamond.	Ehrhardt	Schneider.	Krupp	Putiloff.	Schneider	Schneider.	Krupp.	Krupp.	Krupp.

The following abbreviations are used:—

Powder:—
G.C. = Guncotton.
N.G. = Nitroglycerin.

Sights:—
P = Panorama.
T = Telescopic.
G. = Goniometric.
O. = Ordinary.

Material of Gun:—
S. = Steel.
N S = Nickel steel.
C S = Chrome steel.
B = Bronze.

Doubtful figures are marked*

In the Krupp guns the track is measured from center to center of each tire.

NOTES.—America:—358 rounds per gun includes 4 rounds on gun carriage.

France:—The high explosive shell weighs 11 68 lbs. only, M. V. 2050 fs. The wagons containing H. E. shell weigh 3 cwt. less than those containing shrapnel.

Germany:—126 rounds per gun, in addition to 103 rounds per gun with light ammunition column. Also 6 H. E. shell per gun are carried in the battery store wagon.

Holland:—The battery, with share of ammunition column, has 1638 rounds, or 272 per gun. The proportion of H. E. shell refers to this total.

Japan: The figures given refer to the 1905 gun. This will be superseded by the 1907 Arisaka gun. *Vide text.*

Norway:—The shield weighs only 56 lbs., and is carried on the wagon.

Spain:—The proportion of ammunition to be carried has been fixed at 64% shrapnel, 16% common, and 20% high explosive.

is the 4.7-in. gun, throwing a 60-lb. projectile, the carriage using the same sights as those of the other guns in the field artillery, using the same methods of checking recoil and the same system of fire control, and requiring no special anchorage or platforms, and thus being truly field artillery.

Light Howitzers.—The flat trajectory fire of guns must be supplemented by curved fire in order to reach defenders behind protection or for the purpose of destroying the protection; hence, both the light and the heavy field guns must be supplemented by a howitzer. The 3.8-in. howitzer now being manufactured by the Ordnance Department could be truly classified as a light howitzer. It has the same weight behind the six-horse team as has the 3-in. gun, and throws a 30-lb. projectile.

The Ordnance Department has also designed a 4.7-in. howitzer, throwing a 60-lb. projectile, which might be classified as either a light howitzer or a heavy howitzer, depending largely upon its use, this use, in turn, depending largely upon its mobility. The howitzer has 6,000 lbs. behind the teams, and if these are composed of eight horses the howitzer could be used as a light howitzer, while if, on the other hand, the teams are composed of but six horses, it would fall into the class of heavy howitzer.

Heavy Howitzers.—This howitzer is designed to supplement the 4.7-in. gun. The howitzer designed by the Ordnance Department has a 6-in. caliber and fires a 120-lb. projectile. The weight behind the teams, 8,000 lbs., is the same as with the 4.7-in. field gun. This howitzer, like both of the others mentioned, has all the laying and sighting appliances of the other ordnance of the field artillery, and also uses the same fire-control system, the same method of checking recoil, requires no anchorage, hold-fasts, platforms, or any preparation previous to its going into action. It is, therefore, clearly a field-artillery weapon.

All the ordnance so far considered fire both high-explosive

shell and shrapnel. The demolition effects of the high-explosive shell are sufficient to break up any field work that can be constructed by the labor of troops.

Siege Artillery.—The term "siege artillery," correctly used, refers to artillery used in investing a besieged or beleagured place. Such artillery would include many different calibers. But the term was used in the act of separating the coast and the field artillery on account of our having in service at that time 5-in. siege guns and 7-in. siege howitzers. These pieces had long been known as "siege artillery," and dated back to a time prior to the development of heavy field artillery, and, consequently, as it was intended that the field artillery should include all mobile artillery, the designation "siege" was put into the law. Since that time, however, these obsolete pieces have been withdrawn from service and are now being replaced by a slightly smaller caliber having much greater power and a weight of about 8,000 lbs. to be drawn by eight horses and thus being mobile enough to accompany infantry in masses.

This term has almost lost any definite meaning, due to the fact that in sieges the largest gun that is practicable is brought up to the front for an investment, and that with increased transportation facilities it has become possible to bring up heavier and heavier guns. Thus, at Port Arthur 11-in. mortars were brought up. Such weapons do not form part of the field artillery, though it may be necessary to have this class of troops handle siege guns. There is no distinct line of demarcation between heavy field artillery and siege artillery. The term really relates more to the use to which the gun is put than to its caliber. But it is generally understood that such artillery comprises guns, howitzers, mortars, etc., that are not permanently horsed, and which do not normally accompany an army, but which are brought up when needed for some specific purpose by utilizing traction engines, railroads, or any similar means of moving the guns, and that

platforms, not infrequently made of concrete, are built, and that when the guns are placed in position they generally stay there until the siege is over. In European armies this class of ordnance is served by fortress artillerymen, a class we do not have in the United States. Most European nations having a land frontier have constructed defensive works along the frontier, which works are manned by guns heavier than field guns and lighter than our large coast-artillery guns, and these are served by fortress artillerymen. When these men are no longer needed in the fortress they move out and take with them such of the ordnance as can be transported by the methods previously stated. In other words, these fortress troops are an intermediate class between our field artillery and our coast artillery. No provision has ever been made in our service for this class of artillery, and probably none ever will be, and therefore the question as to whether the field or the coast artillery will handle such guns is one that has never been settled. There can, however, be no doubt but that heavy field artillery, including all the calibers that have been mentioned in this article, properly belongs to field-artillery troops, and, under the law, must be handled by them.

PART I

AN ELEMENTARY COURSE OF MATHEMATICS FOR FIELD ARTILLERYMEN

Taken from Artillery Circular H, June 1, 1893.

COURSE IN MATHEMATICS FOR ARTILLERY GUNNERS

CHAPTER I

DEFINITIONS AND USE OF MATHEMATICAL SIGNS

Mathematics is the *science of quantity.*

Science is an arrangement of the principles of any subject in regular and proper order.

Quantity is anything that can be increased, diminished, or measured. To measure a quantity is to find how many times it contains some other quantity of the same kind, called the *unit of measure.* A *unit* is a single thing of any kind.

In *pure mathematics,* or mathematics which considers quantity without regard to matter, there are but eight kinds of quantity, and hence only eight kinds of units, viz.: Units of *number,* of *length,* of *surface,* of *volume,* of *weight,* of *time,* of *currency,* and of *angular measure.*

Quantity includes *number* and *magnitude.* A *number* is one or more units; a *magnitude* anything that can be measured. Number answers the question How many? magnitude, How much?

Arithmetic is the *science of numbers.* In arithmetic numbers are usually expressed by figures; as 1, 2, 3, etc. Numbers are called *abstract* when the *kind of unit* is *not* named; as one, two, three, etc.; *denominate,* when the unit is named; as one yard, two pounds, three seconds, etc.

A *problem* is a question regarding quantity proposed for solution.

A *solution* is a statement of the mathematical work done to obtain the answer to a problem.

A *rule* is a general direction for solving problems of the same kind.

In stating mathematical work it is often convenient to indicate by characters, called *mathematical signs,* what is to be done with the quantities considered, or the relations which exist between them.

The signs most used in arithmetic are $+$, $-$, $\times$, $\div$, and $\sqrt{}$, which indicate work to be done, and are called *signs of operation,* and ——, (), [], $=$, :, and ::, which show relation between or among quantities, and are called *signs of relation.*

$+$ is the *sign of addition,* and is read "*plus.*" The numbers between which it is placed are to be added. Thus: $4 + 2$, is read "4 *plus* 2," and equals 6.

$-$ is the *sign of subtraction,* and is read "*minus.*" When placed between two numbers, the one on the right is to be taken from that on the left. Thus: $5-3$ is read "5 *minus* 3," and equals 2.

$\times$ is the *sign of multiplication,* and is read "*multiplied by,*" or "*times.*" The numbers between which it is placed are to be multiplied together. Thus 4×5 is read "4 *multiplied by* 5," or "4 *times* 5," and equals 20.

$\div$ is the *sign of division,* and is read "*divided by.*" When placed between two numbers, the one on the left is to be divided by that on the right. Thus: $6 \div 3$ is read "6 *divided by* 3," and equals 2.

——, (), and [] are *signs of aggregation,* or of bringing together. The first is the *vinculum;* the second, the *parentheses;* the third, the *brackets.* They are used for the same purpose—to connect several quantities. Numbers placed under the vinculum, or within the parentheses or brackets, are to be considered as *one quantity.* Thus: $6 - \overline{3 + 2}$, or $6 - (3+2)$, or $6-[3+2]$ means that the sum of $3+2$ is to be taken from 6. Brackets are ordinarily used only when the total

relation can not be shown by means of a single vinculum or parentheses.

$=$ is the *sign of equality*, and is read "*is equal to*," or "*equals.*" Quantities between which it is placed are equal. Thus: $\overline{3+2}\times4=(6+4)\times2=[(3+2)\times(9-1)]\div2=20$.

$\surd$ is the *radical sign*; :, the *sign of ratio*; ::, the *sign of proportion.* Their uses will be explained hereafter.

Arithmetic depends on the general principle that any number may be increased or diminished. The fundamental operations of arithmetic are *addition, subtraction, multiplication*, and *division. Multiplication* is simply a short method of adding equal numbers; *division*, a short method of making several subtractions of the same number. Thus: 5 can be multiplied by 4 by adding four 5's together; and 20 can be divided by 5, or how many times 20 contains 5 can be found by subtracting four 5's from 20.

Numbers are therefore classified as *positive numbers*, or numbers to be added together; and *negative numbers*, or numbers to be subtracted from positive numbers, but added to other negative numbers. *Positive numbers* are preceded by the sign $+$; *negative numbers* by the sign $-$. When a number has no sign before it, it is considered positive.

In every mathematical expression a $+$ or a $-$ affects the *whole result* of the work indicated *between* it and the *next* following $+$ or $-$, or, between it and the end of the expression. In no case can a $\times$ or a $\div$ affect any quantity before the preceding, or beyond the following $+$ or $-$. Thus: in the expression $5+7\times3\times6-4\times3$, the $+$ indicates the addition of 126, not of 7 only; and the $-$ indicates the subtraction of 12. The same meaning is better expressed by $5+(7\times3\times6)-(4\times3)$.

The signs $\times$ and $\div$ simply show what operations are to be performed on the positive or negative numbers which precede them. When they occur in succession they have their effects in the order of their occurrence. Thus: in the expression $[30-(6\times4)]\div3$, the sign $\times$ shows that 6 is to be multi-

plied by 4, but it does not show what is to be done with the resulting 24; *this* is shown by the −. 24 is to be taken from 30, and the remainder divided by 3.

PROBLEMS.

1. $4\times3+7\times2-9\times3+6\times4-3\times3=$ what? Ans. 14.

Solution: $4\times3=12$; $7\times2=14$; $-9\times3=-27$; $6\times4=24$; $-3\times3=-9$. Grouping according to the + and − signs, and adding, we have, $12+14+24=50$; and $-27-9=-36$. Therefore, $50-36=14$, Ans.

2. $8\times2-9\div3+4\times5-6\div3-7\times5=$ what? Ans. −4.

Solution: $16-3+20-2-35$. Grouping and adding, we have, $36-40=-4$, Ans.

3. $21\div3\times7-1\times1\div1\times4\div2+18\div3\times6\div(2\times2)+(4-2+6-7)\times4\times6\div8=$ what? Ans. 59.

Solution: Performing operations indicated between + and − signs, we have $49-2+9+3$, or $61-2=59$, Ans.

4. $16\times4\div8-7+48\div16-3+24\times6\div48-4\times9\div12-1=$ what? Ans. 0.

5. $(16\div16\times96\div8-7-5+3)\times[(24\div4)\div3-1]+(91\div13\times7-45-3)\times9=$ what? Ans. 12.

6. $(12+4\times\overline{9\div3})\times[(\overline{2+5\times2}\div\overline{1+4\times3-10})\div2-1]\div[28-2\times(3\times\overline{2+8}\div4)-2]=$ what? Ans. 12.

CHAPTER II

COMMON FRACTIONS

A *fraction* is one or more equal parts of a *divided unit.*

A *whole number* is one or more units.

A *mixed number* consists of a whole number and a fraction.

Fractions are divided into two classes—*common fractions* and *decimal fractions;* the former are ordinarily called simply *fractions;* the latter, when expressed as hereafter explained, *decimals.*

A common fraction is expressed by writing one number above and another below a line. Thus: $\frac{3}{4}$ is a common fraction which is read "*three-fourths.*" The number above the line is called the *numerator;* that below, the *denominator.* The numerator and denominator are called the *terms* of the fraction.

A *proper fraction* is one whose numerator is *less than* its denominator; as, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{5}{6}$.

An *improper fraction* is one whose numerator is *equal to* or *greater than* its denominator; as $\frac{2}{2}$, $\frac{2}{1}$, $\frac{4}{3}$.

A whole number may be expressed as an improper fraction by writing 1 for its denominator. Thus $4=\frac{4}{1}$; $5=\frac{5}{1}$.

A mixed number may be expressed as an improper fraction by multiplying the whole number by the denominator of the fraction, to the product adding the numerator and writing the sum over the denominator. Thus: $2\frac{3}{5}=\frac{13}{5}$; $3\frac{3}{4}=\frac{15}{4}$.

Cancellation.

Cancellation is a process by which operations in fractions may often be shortened. It depends on the principle that if

both terms of an expression, written as a fraction and in which the terms are products of two or more numbers, be divided by the same number the value of the expression will not be changed. Any number that will exactly divide both terms is called a *common factor*.

A *factor* of a number is any number, except 1 and the number itself, that will exactly divide it.

Cancellation consists in omitting or *canceling* all common factors in an expression such as that just referred to. To perform this operation—

Cancel all common factors, and divide the product of the remaining factors of the numerator by the product of the remaining factors of the denominator.

Thus: $$\frac{63\times 12}{42\times 16}=\frac{\cancel{7}\times\cancel{3}\times 3\times 3\times\cancel{2}\times\cancel{2}}{\cancel{7}\times\cancel{3}\times\cancel{2}\times\cancel{2}\times 2\times 2\times 2}=\frac{9}{8}.$$

If all the factors of either the numerator or denominator are canceled, 1 must be written for the last factor canceled.

Reduction of Fractions.

Reduction of fractions consists in changing their form without altering their value.

Case I.—To reduce a fraction to its lowest terms.

A fraction is reduced to its lowest terms when all factors common to both terms have been canceled.

Rule.—*Cancel all common factors.*

PROBLEMS.

Reduce to their lowest terms—

1. $\frac{42}{189}$. Ans. $\frac{2}{9}$.
2. $\frac{105}{195}$. Ans. $\frac{7}{13}$.
3. $\frac{154}{210}$. Ans. $\frac{11}{15}$.
4. $\frac{156}{221}$. Ans. $\frac{12}{17}$.
5. $\frac{253}{414}$. Ans. $\frac{11}{18}$.
6. $\frac{667}{783}$. Ans. $\frac{23}{27}$.

CASE II.—TO REDUCE FRACTIONS TO A COMMON DENOMINATOR.

Fractions have a common denominator when their denominators are alike.

Before performing the operation, express mixed numbers as improper fractions, and reduce all fractions to their lowest terms.

RULE.—*Multiply both terms of each fraction by the denominators of all the other fractions.*

PROBLEMS.

Reduce to a common denominator

1. $\frac{1}{2}, \frac{2}{3}, \frac{3}{5}$. Ans. $\frac{15}{30}, \frac{20}{30}, \frac{18}{30}$.
2. $\frac{2}{3}, \frac{3}{7}, \frac{5}{8}$. Ans. $\frac{112}{168}, \frac{72}{168}, \frac{105}{168}$.
3. $\frac{6}{9}, \frac{9}{12}, \frac{12}{20}, \frac{15}{18}$. Ans. $\frac{240}{360}, \frac{270}{360}, \frac{216}{360}, \frac{300}{360}$.
4. $1\frac{2}{3}, 2\frac{3}{6}, 3\frac{3}{4}, 2\frac{8}{10}$. Ans. $\frac{200}{120}, \frac{300}{120}, \frac{450}{120}, \frac{336}{120}$.

ADDITION OF FRACTIONS.

RULE.—*Reduce the fractions to a common denominator, add their numerators, and write the sum over the common denominator.*

When there are mixed numbers, add whole numbers and fractions separately and then add their sum. After adding, reduce the result to its lowest terms.

PROBLEMS.

1. $\frac{2}{3}+\frac{3}{5}+\frac{7}{9}+\frac{4}{15}=$what? Ans. $2\frac{14}{45}$.
2. $\frac{3}{8}+\frac{1}{22}+\frac{7}{24}+\frac{29}{88}=$what? Ans. $1\frac{1}{24}$.
3. $\frac{6}{10}+\frac{4}{14}+\frac{8}{12}+2\frac{1}{3}=$what? Ans. $3\frac{31}{35}$.
4. $1\frac{1}{2}+2\frac{1}{3}+3\frac{1}{4}+4\frac{1}{5}=$what? Ans. $11\frac{17}{60}$.

SUBTRACTION OF FRACTIONS.

RULE.—*Reduce the fractions to a common denominator and write the difference of their numerators over the common denominator.*

When there are mixed numbers and the numbers are small, express them as improper fractions and then subtract; if the numbers are not small, subtract whole numbers and fractions separately and then unite the results.

If the fraction of the subtrahend is greater than that of the minuend, take a unit from the whole number of the minuend, add to its fraction, and then subtract. After subtracting, reduce the remainder to its lowest terms.

PROBLEMS.

1. $\frac{4}{5}-\frac{5}{12}=$what? Ans. $\frac{23}{60}$.
2. $\frac{33}{42}-\frac{4}{63}=$what? Ans. $\frac{13}{18}$.
3. $7\frac{5}{12}-3\frac{1}{2}=$what? Ans. $3\frac{11}{12}$.
4. $5\frac{23}{32}-2\frac{2}{7}=$what? Ans. $3\frac{97}{224}$.

Multiplication of Fractions.

Rule.—*Multiply the numerators together for a new numerator and the denominators for a new denominator.*

Before multiplying, indicate the operation and employ cancellation when applicable. Whole and mixed numbers should be expressed as improper fractions.

PROBLEMS.

1. $\frac{12}{35}\times\frac{7}{16}=$what? Ans. $\frac{3}{20}$.
2. $\frac{7}{9}\times45=$what? Ans. 35.
3. $32\times2\frac{3}{8}=$what? Ans. 76.
4. $12\frac{3}{8}\times3\frac{3}{11}=$what? Ans. $40\frac{1}{2}$.
5. $\frac{3}{5}\times\frac{7}{9}\times\frac{9}{11}\times3\frac{1}{3}\times3\frac{1}{7}=$what? Ans. 4.
6. $3\frac{1}{2}\times4\frac{2}{3}\times5\frac{3}{5}\times\frac{2}{9}\times\frac{5}{14}\times6\frac{3}{4}=$what? Ans. 49.

Division of Fractions.

Rule.—*Invert the terms of the divisor and multiply the resulting fraction by the dividend.*

Before multiplying, indicate the operation and employ cancellation when applicable. Whole and mixed numbers should be expressed as improper fractions.

PROBLEMS.

1. $\frac{3}{4} \div \frac{1}{2}$—what? Ans. $1\frac{1}{2}$.
2. $1\frac{3}{4} \div 5 =$ what? Ans. $\frac{7}{20}$.
3. $19\frac{1}{2} \div 1\frac{7}{8} =$ what? Ans. $10\frac{2}{5}$.
4. $8\frac{1}{6} \div \frac{2}{3} =$ what? Ans. $12\frac{1}{4}$.
5. $73\frac{1}{2} \div 9\frac{4}{5} =$ what? Ans. $7\frac{1}{2}$.
6. $54\frac{43}{48} \div 25\frac{5}{6} =$ what? Ans. $2\frac{1}{8}$.

GENERAL PROBLEMS.

1. $3\frac{1}{4} + 4\frac{2}{5} - 5\frac{1}{2} + 16\frac{5}{8} - 7\frac{11}{24} + 10 - 14\frac{5}{6} =$ what? Ans. $6\frac{29}{60}$.
2. $\frac{7}{11} \times 2\frac{1}{2} \times \frac{3}{13} \times 19\frac{1}{2} =$ what? Ans. $7\frac{7}{44}$.
3. $(\frac{7}{8} \times \frac{5}{9} \times 14\frac{1}{7}) \div (\frac{3}{11} \times \frac{2}{7} \times 13\frac{4}{9}) =$ what? Ans. $6\frac{9}{16}$.
4. $[(4\frac{1}{3} \times 4\frac{1}{3} \times 4\frac{1}{3}) - 1] \div [(4\frac{1}{3} \times 4\frac{1}{3}) - 1] =$ what? Ans. $4\frac{25}{48}$.
5. $[(2+\frac{1}{5}) \div (3+\frac{1}{7})] \div [(2-\frac{1}{3}) \times (4-3\frac{3}{7})] =$ what? Ans. $\frac{147}{200}$.
6. $\dfrac{4}{5\frac{1}{3}} \times 14\frac{1}{7} \times \dfrac{2\frac{3}{4}}{4} \times \dfrac{5}{7\frac{1}{3}} \times \dfrac{1\frac{1}{5}}{2\frac{3}{4}} \times 6 =$ what? Ans. $13\frac{1}{56}$.

CHAPTER III

DECIMAL FRACTIONS

A *decimal fraction* is a fraction whose denominator is 10, or some product of 10 expressed by 1 with ciphers annexed. Thus: $\frac{1}{10}$, $\frac{13}{100}$, $\frac{125}{1000}$ are decimal fractions.

Decimal fractions are ordinarily expressed by writing the numerator, with ciphers prefixed when necessary, after a dot, or period (.), called the *decimal point,* and omitting the denominator. Decimal fractions *when so written* are called *decimals.*

The places of figures on the right of the decimal point are called *decimal places;* the first is *tenths;* the second, *hundredths;* the third, *thousandths;* the fourth, *ten-thousandths;* and so on. Thus: $\frac{1}{10}$ is written .1, and read "*one-tenth*"; $\frac{4}{100}$ is written .04, read "*four hundredths*"; $\frac{31}{1000}$ is written .031, read "*thirty-one thousandths*"; $\frac{517}{10000}$ is written .0517, read "*five hundred and seventeen ten-thousandths.*" From this it is seen that the denominator of the decimal fraction corresponding to any decimal is 1 with as many ciphers annexed as there are decimal places in the decimal; and that any decimal is read by reading the number after the decimal point as a numerator, and adding to the number thus read the name of the last, or right-hand, decimal place.

A *pure decimal* consists of single figures or ciphers in its decimal places only; as .215.

A *mixed decimal* consists of a whole number and a pure decimal; as 3.215.

A *complex decimal* consists of a pure or mixed decimal and a common fraction; as $3.215\frac{1}{3}$.

Reduction of Decimals.

Reduction of decimals consists in changing their form without altering their value.

Case I.—To reduce a decimal to a common fraction.

Rule.—*Write the decimal as a decimal fraction and reduce this fraction to its lowest terms.*

PROBLEMS.

Reduce .25 to a common fraction.

Solution: $.25 = \frac{25}{100} = \frac{1}{4}$, Ans.

PROBLEMS.

Reduce to common fractions—

1. .25625. Ans. $\frac{41}{160}$.
2. .003125. Ans. $\frac{1}{320}$.
3. 2.125. Ans. $2\frac{1}{8}$.
4. 19.01750. Ans. $19\frac{7}{400}$.
5. $3.33\frac{1}{3}$. Ans. $3\frac{1}{3}$.
6. $11.0\frac{5}{9}$. Ans. $11\frac{1}{18}$.

Case II.—To reduce common fractions to decimals.

Rule.—*Annex ciphers to the numerator and divide it by the denominator. Then point off from the right of the quotient as many decimal places as there are ciphers annexed.*

PROBLEM.

Reduce $\frac{1}{8}$ to a decimal.

Solution:
$$\begin{array}{r} 8)\underline{1.000} \\ .125, \text{ Ans.} \end{array}$$

Any fraction in its lowest terms having in its denominator any factor other than 2 or 5 can not be reduced to a pure decimal. Thus: $\frac{1}{12} = .0833\frac{1}{3}$, or $.0833+$; and $\frac{1}{6} = .1666\frac{2}{3}$, or

.1667−. The sign + is used at the end of a decimal to indicate that the last figure is too small; the sign −, to indicate that it is too great.

By the rule, a mixed number may be converted into a mixed, or a complex, decimal; and a complex decimal having no other factor than 2 or 5 in the denominator of the common fraction into a pure decimal. Thus: $9\frac{1}{4}=9.25$, since $\frac{1}{4}=.25$; $3\frac{1}{3}=3.33\frac{1}{3}$, since $\frac{1}{3}=.33\frac{1}{3}$, and $.26\frac{1}{25}=.2604$, since $\frac{1}{25}=.04$.

PROBLEMS.

Reduce to decimals—

1. $\frac{15}{32}$. Ans. .46875.
2. $\frac{5}{64}$. Ans. .078125.
3. $\frac{13}{256}$. Ans. .05078125.
4. $42\frac{3}{16}$. Ans. 42.1875.
5. $19\frac{3}{80}$. Ans. 19.0375.
6. $2.0\frac{1}{320}$. Ans. 2.0003125.

Addition of Decimals.

Rule.—*Write the numbers to be added so that the decimal points shall be in the same column; then add as in whole numbers and place the decimal point in the sum directly under the decimal points above.*

Complex decimals, if there be any, must be made pure as far as the decimal places extend in the other numbers.

PROBLEMS.

1. 14.034+25+.0000625+.0034=what? Ans. 39.0374625.
2. 216.86301+48.1057+.029+1.3=what? Ans. 266.29771.
3. $16\frac{2}{3}+.37\frac{1}{2}+3.4\frac{3}{8}+.000\frac{7}{8}$=what? Ans. $3.980\frac{1}{24}$.
4. $.11\frac{1}{9}+.6666\frac{2}{3}+.222222\frac{2}{9}$=what? Ans. 1.
5. 35.+3.5+.35+.035=what? Ans. 38.885.
6. $.14\frac{2}{7}+.018\frac{3}{5}+920+.0139\frac{3}{7}$=what? Ans. 920.1754.

Subtraction of Decimals.

Rule.—*Write the less number under the greater so that the decimal points shall be in the same column; then subtract as in whole numbers and place the decimal point in the remainder directly under those above.*

If either or both of the decimals be complex, extend them to the same decimal place before subtracting.

If the greater number has not as many decimal places as the smaller, annex 0's until it has the same.

PROBLEMS.

1. $19.54 - 8.00717 =$ what? Ans. 11.53283.
2. $19. - 8.999\frac{1}{9} =$ what? Ans. $10.000\frac{8}{9}$.
3. $3.701 - 2.4\frac{1}{2} =$ what? Ans. 1.251.
4. $1.169\frac{3}{7} - .93\frac{2}{35} =$ what? Ans. $.238\frac{6}{7}$.
5. $4.9\frac{3}{8} - .01\frac{1}{2} =$ what? Ans. 4.9225.
6. $.0\frac{1}{18} - .00\frac{5}{9} =$ what? Ans. 0.

Multiplication of Decimals.

Rule.—*Multiply as in whole numbers and point off in the product, from the right hand, as many decimal places as there are in both numbers multiplied together; if there be not so many in the product, supply the deficiency by prefixing* 0*'s.*

PROBLEMS.

1. $64.01 \times .32 =$ what? Ans. 20.4832.
2. $34. \times .193 =$ what? Ans. 6.562.
3. $2.7 \times .4\frac{1}{5} =$ what? Ans. 1.134.
4. $21.0375 \times 4.44\frac{4}{9} =$ what? Ans. 93.5.
5. $.02\frac{1}{4} \times 600 =$ what? Ans. 13.5.
6. $1.006 \times .0001 =$ what? Ans. $.0001006$.

Division of Decimals.

Rule.—*Divide as in whole numbers and point off in the quotient, from the right hand, as many decimal places as those in the dividend exceed those in the divisor; if there be not so many in the quotient, supply the deficiency by prefixing* 0*'s.*

When there are more decimal places in the divisor than in the dividend, annex 0's to the latter until the number in both is the same. *The quotient will then be a whole number.*

When it is necessary to continue the division farther than the figures of the dividend will allow, annex 0's and consider them as decimal places of the dividend.

PROBLEMS.

1. $.0001 \div .01 =$ what? Ans. .01.
2. $1,000 \div .001 =$ what? Ans. 1,000,000.
3. $.0001 \div 1000 =$ what? Ans. .0000001.
4. $12.9 \div 8.256 =$ what? Ans. 1.5625.
5. $3.15 \div 375 =$ what? Ans. .0084.
6. $10.1 \div 17 =$ what? Ans. .59412−.

CHAPTER IV

TABLES OF MEASURE

In pure mathematics, as before stated, there are but eight different kinds of quantity. For measuring each kind of quantity, there are, however, one or more *systems of measurement*, and each system has, for convenience, a number of subdivisions. Quantities expressed in terms of the same subdivision are said to be of the same *denomination.*

A *table of measure* is a series of numbers showing the relation between the different subdivisions of a system of measurement for a particular kind of quantity.

A *measure* is a unit for measuring quantities of the same denomination.

A *standard unit* is a measure made a standard, by law or custom, for comparison of all measures of the same system.

The following are some of the tables of measure in ordinary use.

Measures of Length.

Long Measure—English System (established in United States by act of Congress in 1834).

TABLE.

12 inches, marked *in.*,	make 1 foot, marked *ft.*
3 feet,	make 1 yard, marked *yd.*
$5\frac{1}{2}$ yards,	make 1 rod, marked *rd.*
320 rods,	make 1 mile, marked *mi.*

EQUAL QUANTITIES.

1 mi. = 1,760 yds. = 5,280 ft.

For measuring horses, the *hand* = 4 in. is the unit; for depths at sea, the *fathom* = 6 ft.; for speed of vessels, the knot = $1\frac{1}{6}$ mi.

LONG MEASURE—METRIC, OR FRENCH, SYSTEM (authorized in the United States by act of Congress in 1866).

TABLE.

10 millimeters, marked *mm.*,	make 1 centimeter, marked *cm.*
10 centimeters,	make 1 decimeter, marked *dm.*
10 decimeters,	make 1 meter, marked *m.*
10 meters,	make 1 dekameter, marked *Dm.*
10 dekameters,	make 1 hektometer, marked *Hm.*
10 hektometers,	make 1 kilometer, marked *Km.*

The *millimeter* and *centimeter* are generally used in measuring very short lengths; the *meter,* for ordinary lengths; and the *kilometer,* for long distances.

COMPARATIVE TABLE.

Denomination.	*Legal Value.*	*Approximate Value.*
1 millimeter.	.03937 inch.	$\frac{1}{25}$ in.
1 centimeter.	.3937 inch.	$\frac{2}{5}$ in.
1 meter.	39.37 inches.	3 ft. $3\frac{3}{8}$ in.
1 kilometer.	.62137 mile.	$\frac{5}{8}$ mi.

MEASURES OF SURFACE.

SQUARE MEASURE—ENGLISH SYSTEM.

TABLE.

144 square inches (*sq. in.*)	make 1 square foot, marked *sq. ft.*
9 sq. ft.	make 1 square yard, marked *sq. yd.*

These measures are used for ordinary surfaces other than land.

SQUARE MEASURE—METRIC SYSTEM.—The *square meter*, marked m^2, and its subdivisions are used for measuring ordinary surfaces other than land.

COMPARATIVE TABLE.

Denomination.	*Legal Value.*	*Approximate Value.*
1 square meter.	1.196 sq. yds.	$10\frac{3}{4}$ sq. ft.

MEASURES OF VOLUME.

CUBIC MEASURE—ENGISH SYSTEM.

TABLE.

1,728 cubic inches (*cu. in.*)	make 1 cubic foot, marked *cu. ft.*
27 cu. ft.	make 1 cubic yard, marked *cu. yd.*

For measuring *firewood*, the *cord* = 4 ft. × 4 ft. × 8 ft. = 128 cu. ft., is the unit; for measuring *board*, the *board foot* = 12 in. × 12 in. × 1 in.

CUBIC MEASURE—METRIC SYSTEM.

The *cubic centimeter* (cm^3) and *cubic meter* (m^3) are used for measuring ordinary volumes.

COMPARATIVE TABLE.

Denomination.	*Legal Value.*	*Approximate Value.*
1 cubic centimeter.	.061 cu. in.	$\frac{1}{16}$ cu. in.
1 cubic meter.	1.308 cu. yds.	$35\frac{1}{3}$ cu. ft.

In the *English* system, for measures of length, surface, and volume, a *yard* measure made of bronze is the *standard unit;* in the *metric* system, a standard *meter*, made of platinum.

Measures of Capacity.

Dry Measure—English System.—Used for measuring all *dry* articles.

TABLE.

2 pints, marked *pt.*,	make 1 quart, marked *qt.*
8 qts.,	make 1 peck, marked *pk.*
4 pks.	make 1 bushel, marked *bu.*

The *standard unit* for dry measure in the United States is the "*Winchester bushel,*" which contains 2,150.42 cu. in. A box 16 in.×16 in.×16.8 in. contains 2,150.4 cu. in., or 1 bushel, very nearly; a box 8 in.×8.4 in.×8 in., 1 peck.

Liquid Measure—English System.—Used for measuring *liquids.*

TABLE.

4 gills, marked *gi.*,	make 1 pint, marked *pt.*
2 pts.	make 1 quart, marked *qt.*
4 qts.	make 1 gallon, marked *gal.*

The *standard unit* for liquid measure in the United States is the gallon, which contains 231 cu. in. A box 6 in.×6 in. ×6.4 in. contains 230.4 cu. in., or 1 gallon, very nearly; a box 4 in.×4 in.×3.6 in., 1 quart.

Dry and Liquid Measures—Metric System.

The *liter,* marked *l,* and the *hektoliter,* marked *Hl,* are the measures ordinarily used.

COMPARATIVE TABLE.

Denomination.	*Legal Value.*	*Approximate Value.*
1 liter.	1.0567 qts.	1 qt.
1 hektoliter.	2.8375 bu.	2 bu. $3\frac{1}{3}$ pks.

Measures of Weight.

English System.—*Avoirdupois weight,* used for weighing all ordinary articles.

TABLE.

16 drams, marked *dr.*,	make	1 ounce, marked *oz.*
16 oz.	make	1 pound, marked *lb.*
25 lbs.	make	1 quarter, marked *qr.*
4 qrs.	make	1 hundredweight, marked *cwt.*
20 cwt.	make	1 ton, marked *T.*

In England 1 cwt. = 112 lbs; 1 ton = 2,240 lbs. These measures are used in the United States for coal and iron.

In the United States artillery, what is called the "troy grain" (7,000 to 1 pound avoirdupois) is taken as the standard for weight.

Metric System.—The *kilogram,* commonly called the "*kilo,*" and the *metric ton* are used in weighing ordinary articles; the *gram,* in cases where great accuracy is required.

COMPARATIVE TABLE.

Denomination.	*Legal Value.*	*Approximate Value.*
1 kilo.	2.2046 lbs. av.	$2\frac{1}{5}$ lbs.
1 metric ton.	2,204.6 lbs. av.	1 T. $204\frac{3}{5}$ lbs.
1 gram.	15.432 grains troy.	$15\frac{1}{2}$ grains.

Measures of Angles.

A *plane angle,* or *an angle* as it is usually called, is the quantity by which two straight lines, starting from a point, separate from each other; or, as often defined for simplicity, it is *the opening between two lines which meet at a point.* The point is called the *vertex*; the lines, the *sides* of the angle.

Thus if two lines, AB and AB^1, at first coincide, and one of them be then moved in the plane of the paper to the positions AB^1, AB^{11}, AB^{111}, and so on, until they again coincide, the opening between the lines, or the angle, will be increased, successively, from its least to its greatest value for one revolution.

Any point on the line AB^1, as b^1, will describe a curved line called a *circumference* of a circle. The portions bb^1, bb^{11}, bb^{111},

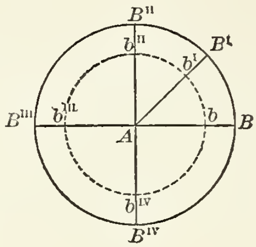


FIG. 1.

bb^{iv} of the circumference show the sizes to which the angle, at first equal 0, has been successively increased; and *since these portions would bear the same relation to each other, no matter what point on the line AB^1 were chosen*, they may be assumed as the *measures of the angles*. For measuring angles circumferences are ordinarily divided as follows:

TABLE.

60 seconds, marked ″,	make 1 minute, marked ′.
60′	make 1 degree, marked °.
360°	make 1 circumference, marked *c*.

CHAPTER V

DENOMINATE NUMBERS

A *denominate number* is one in which a quantity is given in one denomination; as 2 feet, 3 yards, 4 pounds.

A *compound denominate number* is one in which a quantity is given in two or more denominations of the same table of measures; as 3 yds. 2 ft. 6 in., or $3° 14' 30''$.

Reduction of Denominate Numbers.

Reduction of denominate numbers consists in changing them from one denomination to another without altering their value.

Case I.—To reduce from a higher to a lower denomination.

Rule.—*Multiply the quantity in the highest denomination by the number of times a unit of this denomination contains one of the next lower, and to the product add the quantity, if any, in the lower denomination. Proceed in like manner with this result and continue the operation until the desired denomination is reached.*

Case II.—To reduce from a lower to a higher denomination.

Rule.—*Divide the given quantity by the number of times a unit of its denomination is contained in one of the next higher. Proceed in like manner with the quotient, and continue the operation until the desired denomination is reached. The last quotient, with the several remainders, if any, annexed in order will be the answer.*

Denominate numbers in the *metric system* are reduced by simply moving the decimal point to the right or to the left.

PROBLEMS.

1. Reduce 6 rds. 4 yds. 2 ft. 9 in. to inches. Ans. 1,365 in.
2. Reduce $15\frac{1}{2}$ hands to feet and inches. Ans. 5 ft. 2 in.
3. Reduce $15° 25' 30''$ to seconds. Ans. $55,530''$.
4. Reduce $8,589''$ to degrees and decimals of a degree. Ans. $2°.386$.
5. Reduce 40 cm. to inches (approximately). Ans. 16 in.
6. Reduce 50 kilos. to pounds (legal value). Ans. 110.23 lbs.

Addition of Compound Denominate Numbers.

RULE.—*Write the quantities, placing numbers of the same denomination in the same column.*

Beginning at the right hand, add the numbers of the lowest denomination and divide the sum by the number of units of this denomination required to make ONE *of the next higher. Write the* REMAINDER *under this denomination and carry the* QUOTIENT *to the next column.*

Add the column of each denomination in the same way.

PROBLEMS.

1. $73° 42' 35''+8° 29' 52''=$ what?

Solution:
$$\begin{array}{r} 73° \; 42' \; 35'' \\ \underline{8° \; 29' \; 52''} \\ 82° \; 12' \; 27'' \end{array} \text{ Ans.}$$

$35''+52''=87''=1' 27''$. The $27''$ is written in the *seconds* column and the $1'$ is carried to the next higher. $42'+29'+1'=72'=1° 12'$. The $12'$ is written in the *minute* column and the $1°$ carried. $73°+8°+1°=82°$.

2. $26° 31' 28''+31° 27' 43''=$ what? Ans. $57° 59' 11''$.

3. $115° 57' 45''+9' 32''=$ what? Ans. $116° 7' 17''$.

4. $10^{yds}\ 2^{ft}\ 10^{in}+7^{yds}\ 1^{ft}\ 7^{in}=$ what? Ans. $18^{yds}\ 1^{ft}\ 5^{in}$

5. $7^{m}\ 6^{dm}\ 5^{cm}\ 4^{mm} + 9^{m}\ 4^{dm}\ 6^{cm}\ 7^{mm}=$ what? Ans. $17^{m}\ 1^{dm}\ 2^{cm}\ 1^{mm}$.

6. $14^{cwt}\ 3^{qr}\ 15^{lb}\ 8^{oz}\ 12^{dr}+12^{cwt}\ 2^{qr}\ 13^{lb}\ 12^{oz}\ 14^{dr}+18^{cwt}\ 3^{qr}\ 12^{lb}\ 9^{oz}\ 10^{dr}=$ what? Ans. $2^{t}\ 6^{cwt}\ 1^{qr}\ 16^{lb}\ 15^{oz}\ 4^{dr}$.

SUBTRACTION OF COMPOUND DENOMINATE NUMBERS.

RULE.—*Write the subtrahend under the minuend so that numbers of the same denomination may be in the same column.*

Beginning at the right hand, subtract the numbers of each denomination separately and write the remainder under the numbers subtracted.

If any number in the subtrahend is greater than the number above it in the minuend, borrow a unit from the next higher denomination of the minuend and reduce it to the next lower denomination, add this to the number in the minuend to be subtracted from, and then subtract.

Proceed in the same way with each denomination, remembering that a number in the minuend from which a unit has been borrowed must be regarded as ONE LESS *than it stands.*

PROBLEMS.

1. $11° \, 14' \, 27'' - 7° \, 28' \, 14'' =$ what?

Solution:

$$\begin{array}{r} 11° \; 14' \; 27'' \\ \underline{7° \; 28' \; 14''} \\ 3° \; 46' \; 13'' \end{array} \text{ Ans.}$$

$27'' - 14'' = 13''$. The remainder $13''$ is written under the numbers subtracted. $28'$ is greater than $14'$. Borrowing $1°$ from the $11°$ of the minuend, reducing this to minutes and adding to $14'$ we have $74'$. $74' - 28' = 46'$. Remembering that $1°$ has been borrowed from the $11°$ we have $10° - 7° = 3°$.

2. $63° \, 47' \, 28'' - 15° \, 28' \, 13'' =$ what? Ans. $48° \, 19' \, 15''$.
3. $75° \, 36' \, 19'' - 18° \, 29' \, 38'' =$ what? Ans. $57° \, 6' \, 41''$.
4. $43° \, 27' \, 15'' - 19° \, 38' \, 17'' =$ what? Ans. $23° \, 48' \, 58''$.
5. $14^{lb} \, 12^{oz} \, 9^{dr} - 6^{lb} \, 14^{oz} \, 11^{dr} =$ what? Ans. $7^{lb} \, 13^{oz} \, 14^{dr}$.
6. $85^{bu} \, 2^{pk} \, 5^{qt} - 58^{bu} \, 3^{pk} \, 2^{qt} \, 1^{pt} =$ what? Ans. $26^{bu} \, 3^{pk} \, 2^{qt} \, 1^{pt}$

Multiplication and *division* of compound denominate numbers may be performed by reducing all numbers to lowest

given denomination, performing the required operation, and then reducing the result to any higher denomination desired.

This method of performing these operations will, it is thought, be sufficient to meet the wants of gunners in ordinary cases.

CHAPTER VI

RATIO AND PROPORTION

A *ratio* is the measure of the relation of one quantity to another of the *same kind and denomination.* It is found by dividing the first quantity by the second, and is always an *abstract number.* Thus, the ratio of 8 ft. to 4 ft. is 2.

The *sign of ratio* is : , which is read "*is to.*" Thus: the ratio of 8 to 4 is written 8 : 4, read "8 *is to* 4," and equals $8 \div 4$, or 2.

A *simple ratio* is the ratio of two quantities. Each quantity is called a *term* of the ratio.

A *proportion* is a comparison of equal ratios.

The *sign of proportion* is :: , which is read "*as*".

A *simple proportion* is a comparison of two equal simple ratios. Thus: 3 : 6 :: 8 : 16, which is read "3 *is to* 6 *as* 8 *is to* 16."

Each quantity in a proportion is called a *term.* The 1st and 4th terms are called the *extremes;* the 2d and 3d, the *means.*

In any proportion *the product of the extremes is equal to the product of the means.* Hence either extreme is equal to the product of the means divided by the other extreme, and either mean is equal to the product of the extremes divided by the other mean.

Simple proportion is employed when three terms are given to find a fourth. Two of the three terms must be of the same denomination and the other of the same as that to be found. The rule by which the fourth term is found is often called the *single rule of three.*

Rule.—*For the 3rd term, write that quantity which is of the same denomination as that to be found. For the 2d term write the greater of the other two quantities when the 4th term is to be greater than the 3d; or the less, when the 4th term is to be less than the 3d. Then divide the product of the 2d and 3d terms by the 1st; the quotient will be the required 4th term.*

If the 1st and 2d terms are quantities of the same kind, but of different denominations, they must be reduced to the same denomination.

If the 3d term is a compound denominate number, it must be reduced to the lowest given denomination.

PROBLEMS.

1. If 6 paces equal 5 yds., how many paces in 100 yds.? Ans. 120 paces.

2. If 1 kilo. equals $2\frac{1}{5}$ lbs, how many lbs. in 50 kilos.? Ans. 110 lbs.

3. If 1 mm. equals $\frac{1}{25}$ in., how many inches in 75 mm.? Ans. 3 in.

4. If 1 cm. equals .3937 in., how many inches in 15 cm.? Ans. 5.91 in.

5. If 1 m. equals 39.37 in., how many meters in 1,000 yds.? Ans. 914.4 m.

6. If 1 Km. equals $\frac{5}{8}$ mi., how many yards in 5 Km.? Ans. 5,500 yds.

CHAPTER VII

PERCENTAGE

Per cent. means *by the hundred.*

The *sign of per cent.* is %, which is read "*per cent.*" Thus: 4% is read "*4 per cent.*," and means $\frac{4}{100}$, or .04.

Percentage is the result obtained by taking a given per cent., or so many hundredths of a given number.

The given per cent., or number of hundredths taken, is called the *rate.*

The number on which the percentage is estimated is called the *base.*

The base *plus* the percentage is called the *amount.*

The relation between the base, rate, and percentage is such that, any two of them being given, the third can be found. *Three* cases may arise.

CASE I.—GIVEN THE BASE AND RATE, REQUIRED THE PERCENTAGE.

RULE.—*Multiply the base by the rate expressed decimally, the product will be the percentage.*

PROBLEMS.

1. 35% of 160 = what?

Solution: $160 \times .35 = 56$, Ans.

2. 5% of 1,900 = what? Ans. 95.

3. $62\frac{1}{2}$% of 1,664 = what? Ans. 1,040.

4. $15\frac{5}{8}$% of 576 = what? Ans. 90.

CASE II.—GIVEN THE BASE AND PERCENTAGE, REQUIRED THE RATE.

RULE.—*Divide the percentage by the base, the quotient will be the rate.*

PROBLEMS.

1. 9 is what % of 45?

Solution: $\frac{9}{45}=\frac{1}{5}=\frac{20}{100}=20\%$, Ans.

2. 95 is what % of 1,900? Ans. 5%.

3. 2 is what % of 15? Ans. $13\frac{1}{3}\%$.

4. 5.12 is what % of 640? Ans. $\frac{4}{5}\%$.

CASE III.—GIVEN THE RATE AND PERCENTAGE, REQUIRED THE BASE.

RULE.—*Divide the percentage by the rate expressed decimally, the quotient will be the base.*

1. 95 is 5% of what?

Solution: $\frac{95}{.05}=1{,}900$, Ans.

2. 3.80 is 5% of what? Ans. 76.

3. 19.20 is $\frac{6}{10}\%$ of what? Ans. 3,200.

4. 189.8 is 104% of what? Ans. 182.5.

CHAPTER VIII

POWERS AND ROOTS

A *power* of a quantity is either the quantity itself or some product of the quantity by itself. The quantity so multiplied is called the *root* of the power.

Powers are named according to the number of times the quantity is multiplied; this is indicated by a small figure called an *exponent*, written to the right of and above the quantity. Thus 2^1 is the *first power* of 2; $2^2=2\times2=4$, is the *second power*, or *square*, of 2; $2^3=2\times2\times2=8$, the *third power*, or *cube* of 2; and so on.

The exponent 1 is ordinarily omitted, and when no exponent is written 1 is understood.

Roots are named according to the number of the times they enter a given power as a factor; this is indicated by what is called the *radical sign*, $\sqrt{}$, or by a *fractional exponent*.

When the *radical sign* is used, a small figure, called an *index*, is placed over the sign to show the *name* of the root if any other than the second, or square, root is to be indicated. Thus: $\sqrt{4}$ indicates the *square root* of 4; $\sqrt[3]{27}$, the *third*, or *cube, root* of 27; $\sqrt[5]{32}$, the *fifth root* of 32. When no index is *written*, the index 2 is always understood.

When a *fractional exponent* is used, the *numerator* indicates a *power;* the *denominator*, a *root*. Thus, $4\sqrt[\frac{1}{2}]{}$ indicates the *first power* and *square root* of 4; $8\sqrt[\frac{2}{3}]{}$ the *second power* of 8 and the *cube root* of the result.

When a root of a quantity can be found exactly, the latter is called a *perfect power* of this root; when it can not be found exactly, an *imperfect power*. Thus: 8 is a *perfect third power*

whose *cube root* is 2; an *imperfect second power,* since its *square root* is 2.8284271+.

Square Root.

The first ten numbers and their squares are—

Numbers:	1	2	3	4	5	6	7	8	9	10
Squares:	1	4	9	16	25	36	49	64	81	100

From this it is evident that the square root of any perfect square, *expressed by two figures,* will be expressed by a single figure.

Case I.—To find the square root of any whole number or decimal.

Rule.—*Separate the number into periods of two figures each, commencing at units or at the decimal point.*

Find the greatest perfect square in the first period on the left; place its root on the right, like a quotient in division; then subtract the square from the period and to the remainder bring down the next period for a dividend.

Double the root figure found and place it on the left for a trial divisor; find how often this is contained in the dividend, exclusive of the right-hand figure, and annex the quotient to the root and to the divisor; multiply the completed divisor by the quotient, subtract the product from the dividend, and to the remainder bring down the next period as before.

Double the whole root found for a new trial divisor, and proceed as before until all the periods have been brought down.

If any trial divisor be greater than its dividend, the corresponding figure of the root will be 0.

If the product of a trial divisor by a figure of the root be greater than the corresponding dividend, the figure of the root is too large.

If the number is not a perfect square, there will be a remainder after all the periods have been brought down. In this

case, periods of two 0's each may be annexed and the operation continued until any desired decimal order of the root is reached.

If the number contains an odd number of decimal places, add a 0.

CASE II.—TO FIND THE SQUARE ROOT OF A COMMON FRACTION.

RULE.—*Find the square roots of the numerator and denominator separately if both are perfect squares; if either is not, reduce the fraction to a decimal and find the square root of this.*

PROBLEMS.

$\sqrt{730.05}$ = what?

Solution:

```
     730.05)27.019+, Ans.
     4
  47)330
     329
5,401)10,500
       5,401
54,029)509,900
       486,261
        23,639, remainder.
```

1. $\sqrt{1,444}$ = what? Ans. 38.
2. $\sqrt{118.81}$ = what? Ans. 10.9.
3. $\sqrt{164,998.44}$ = what? Ans. 406.2.
4. $\sqrt{272\frac{3}{12}}$ = what? Ans. $16\frac{1}{2}$.
5. $\sqrt{\frac{6}{7}}$ = what? Ans. .9258+.
6. $\sqrt{6\frac{2}{5}}$ = what? Ans. 2.5298+.

CHAPTER IX

GEOMETRICAL MAGNITUDES

A *geometrical magnitude* is a quantity that has either *length, breadth, thickness* or *form.*

There are four kinds of geometrical magnitudes: *lines, surfaces, solids,* and *angles.* A *point* has *position,* but not *magnitude.*

Some of the subdivisions of these magnitudes are as follows:

LINES.

A *line* is a magnitude that has *length* only.

A *straight line* is a line that does not change direction at any point.

A *curved* line is a line that changes direction at every point.

A straight line is ordinarily called a *right line,* or simply a *line;* a curved line, a *curve.*

[For simplicity, the following definitions regarding surfaces and angles are here given:

A *surface* is a magnitude that has length and breadth, but not thickness.

A *plane surface,* or *plane,* is a surface in which a straight line, joining any two points in the surface, will wholly lie.

A *plane angle,* or an *angle,* as before defined, is the opening between two straight lines which meet at a point; as a magnitude it has *form,* but neither length, breadth, nor thickness.

A *right angle* is an angle measured by 90°.]

Parallel lines are lines, in the same plane, which would not

meet however far either way both of them might be extended; as the lines *AB, CD.* (Fig. 2.)

Fig. 2.

Perpendicular lines are straight lines at right angles to each other; as the lines *AB, CD.* (Fig. 3.)

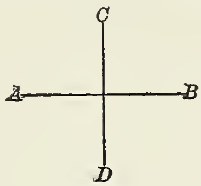


Fig. 3.

A *vertical line* is one that points toward the center of the earth. A plummet is ordinarily used to determine this direction.

A *horizontal line* is one at right angles to a vertical line. It is parallel to the horizon, or sea level, and may be determined by means of a plummet and carpenter's square or by a carpenter's level.

Angles.

An *acute angle* is one that is *less* than a right angle; as the angle *BAC.* (Fig. 4.)

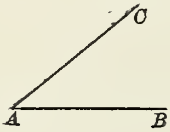


Fig. 4.

An *obtuse angle* is one that is *greater* than a right angle; as the angle *CAB*. (Fig. 5.)

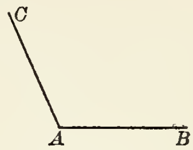


Fig. 5.

When one straight line intersects another the four angles formed are named according to their relative positions, thus:

Adjacent angles are the two angles on the same side of either line; as the angles *AOC* and *COB* are *adjacent.*

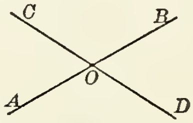


Fig. 6.

Opposite angles are either pair of those which point in opposite directions; as *AOD* and *COB*.

When one straight line intersects two parallel lines the angles within the parallels on different sides of the intersecting line, but not adjacent, are called *alternate angles;* as *AHG* and *HGD*.

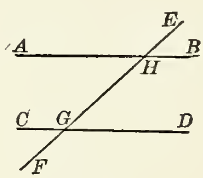


Fig. 7.

An *interior angle* is an angle formed inside of an inclosed figure by the meeting of two of its sides; as *ABC*.

An *exterior angle* is an angle formed outside the figure by any side and the prolongation of an adjacent side; as aAB.

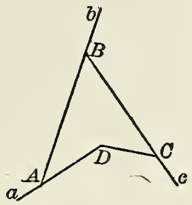


Fig. 8.

A *reëntering angle* is one that points *inward,* as ADC; a *salient angle,* one that points *outward,* as ABC.

Surfaces.

A *curved surface* is a surface no part of which is a plane.

A polygon is a plane surface bounded by straight lines.

A regular polygon is one whose sides are equal.

Polygons are named according to the number of their sides; one of three sides is a *triangle;* of four, a *quadrilateral;* of five, a *pentagon;* of six a *hexagon;* and so on.

The following diagrams represent regular polygons:

POLYGONS

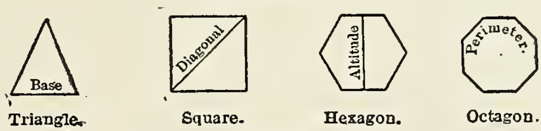


Fig. 9.

A diagonal of a polygon is a straight line joining any two angles not adjacent.

The *base* is the side on which the polygon stands.

The *altitude* is the perpendicular distance from the base to the highest point, or one of the highest points, of the polygon.

The *perimeter* of a polygon is its bounding line.

TRIANGLES.—*Triangles* are classified according to the relative lengths of their sides, and also according to the nature of their angles.

A *scalene triangle* has no two sides equal; an *isosceles triangle* has two, and only two, sides equal; and an *equilateral triangle* has three sides equal.

An *acute-angled triangle* has three *acute* angles; an *obtuse-angled triangle,* one *obtuse* angle; a *right-angled triangle,* one right angle. In a right-angled triangle the side opposite the right angle is called the *hypotenuse;* the other sides, the *base* and the *perpendicular.*

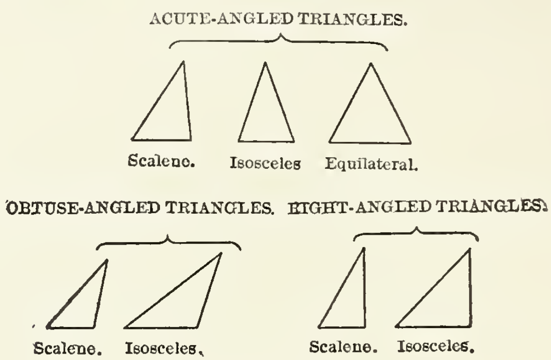


FIG. 10.

QUADRILATERALS.—*Quadrilaterals* are classified according to the relative directions of their sides.

A *trapezium* has no two sides parallel; a *trapezoid* has two, and only two, sides parallel; a *parallelogram* has two pairs of parallel sides.

Parallelograms are classified according to the nature of their angles.

A *rhomboid* is a parallelogram with no right angle; a *rectangle,* one with four right angles.

A *rhombus* is an equilateral rhomboid; a *square,* an equilateral rectangle.

CIRCLES.—A *circle* is a plane surface bounded by a curved line every point of which is equally distant from a point within, called the *center*.

A *circumference* is the curved bounding line of a circle.

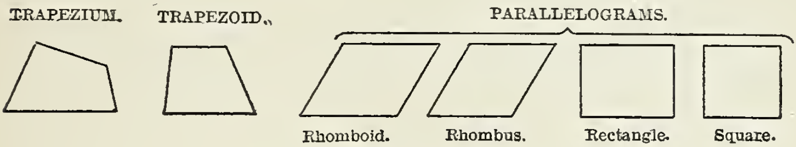


FIG. 11.

A *diameter of a circle* is any straight line drawn through the center and ending each way in the circumference.

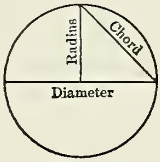


FIG. 12.

A *radius of a circle* is any straight line drawn from the center to the circumference.

An *arc of a circle* is any portion of the circumference; a *chord of an arc* is the straight line which joins its extremities.

SOLIDS.

A *solid* is a magnitude that has length, breadth and thickness. It may have plane or curved bounding surfaces, or both. If the bounding surfaces are planes, they are called the *faces* of the solid, and the lines of intersection of the faces are called the *edges*.

A *prism* is a solid having two of its faces equal and parallel polygons and the other faces parallelograms. The parallel polygons are called *bases;* and the perpendicular distance between them the *altitude* of the prism. The parallelograms are called *lateral faces,* and when taken together they constitute the *convex surface* of the prism.

When *all* the lateral faces are rectangles, the prism is called a *right prism;* when *some* are rhomboids, an *oblique prism.*

Prisms are named according to the form of their bases, as *triangular, quadrangular, pentangular, hexangular,* etc.

When the *bases* and *faces* of a prism are *squares,* the prism is called a *cube.*

When the bases of a prism are *circles,* or regular polygons of an infinite number of sides, the prism is called a *cylinder.* When a perpendicular through the center of one base also passes through the center of the other, a cylinder is called a *right cylinder;* when it does not, an *oblique cylinder.*

FIG. 13.

A *pyramid* is a solid having for one of its faces any polygon and for the others triangles which meet at a common point.

The polygon is called the *base*; the triangles, the *lateral faces;* and the point at which the triangles meet, *the vertex.* The perpendicular distance from the vertex to the plane of the base is called the *altitude.* The lateral faces taken together constitute the *convex surface.*

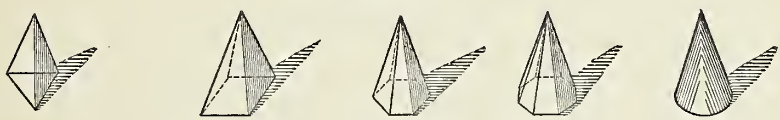
A *right pyramid* is one whose base is a regular polygon and whose lateral faces are isosceles triangles. In this case the

perpendicular from the vertex to the plane of the base passes through the center of the base, and is called the *axis* of the pyramid; and a perpendicular from the vertex to any side of the base passes through the middle of the side, and is called the *slant* height of the pyramid.

Pyramids are named according to the shape of their bases, as *triangular, quadrangular, pentangular, hexangular,* etc.

When the base of a pyramid is a *circle,* or regular polygon of an infinite number of sides, the pyramid is called a *cone.* When a perpendicular from the vertex to the plane of the base passes through the center of the base, the cone is a *right cone,* and its *slant height* is the distance from the vertex to the circumference of the base.

PYRAMIDS



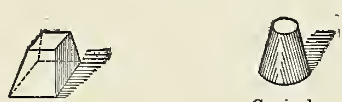
Triangular. Quadrangular. Hexangular. Octangular. Cone.

FIG. 14.

A *frustum* of a pyramid or cone is the portion which remains when the top is cut off by a plane parallel to the base. The *altitude* of a frustum is the perpendicular distance between its parallel bases.

The *slant height* and *axis* of a frustum of a right pyramid or right cone are the portions of the slant height or axis of

FRUSTUMS



Quadrangular. Conical.

FIG. 15.

the pyramid or cone included between the bases of the frustum.

Frustums are named according to the shape of their

bases, as *triangular, quadrangular, hexangular, octangular, conical.*

Spheres—A *sphere* is a solid bounded by a curved surface every point of which is equally distant from a point within called the *center.* A *diameter* of a sphere is a straight line

SPHERE

passing through the center and ending each way in the surface; a *radius* is a straight line drawn from the center to any point of the surface.

Every section of a sphere by a plane is a circle; any section by a plane through the center is called a *great circle.*

CHAPTER X

MENSURATION

Mensuration is the art of computing *lengths, areas,* and *volumes* of geometrical magnitudes by arithmetical rules.

A *length* is a definite portion of a line in terms of its unit of measure; an *area,* that of a surface; a *volume,* that of a solid.

The unit of measure of a surface is a *square;* of a volume, a *cube.*

LENGTHS.

Sides of a right-angled triangle.

I.—To find hypotenuse when base and perpendicular are given.

Rule.—*Add the squares of base and perpendicular and extract square root of the sum.*

II.—To find base or perpendicular when the hypotenuse and either side are given.

Rule.—*From the square of hypotenuse subtract the square of the given side and extract the square root of the remainder.*

PROBLEMS.

1. Base equals 4.8 ft.; perpendicular, 3.6 ft.; what is hypotenuse? Ans. 6 ft.

2. Base equals 15 yds.; perpendicular, 9 yds. 1 ft.; what is hypotenuse? Ans. 17 yds. 2 ft.

3. Hypotenuse equals 67.43 yds.; perpendicular, 52.6; what is the base? Ans. 42.17+.

4. Hypotenuse equals 52.32 ft.; base, 32.11; what is perpendicular? Ans. 41.30+.

Lines of a Circle.

The ratio of the circumference of a circle to the diameter is 3.1415926+, which ratio is represented by the Greek letter π, called *pi.*

I.—To find the circumference when the diameter is given.

Rule.—*Multiply the diameter by 3.1416.*

II.—To find the diameter when the circumference is given.

Rule.—*Divide the circumference by 3.1416.*

PROBLEMS.

1. Diameter equals 3.2 in.; what is the circumference? Ans. 10.05 in.

2. Diameter equals 1 ft. 3 in.; what is the circumference? Ans. 3 ft. 11.12 in.

3. Circumference equals 63.9 ft.; what is the diameter? Ans. 20.34 ft.

4. Circumference equals 6 yd. 1 ft. 4 in.; what is the diameter in feet? Ans. 6.154 ft.

Areas.

Triangle.

I.—To find area when base and altitude are given.

Rule.—*Multiply the base by half the altitude.*

II.—To find area when three sides are given.

Rule.—*From half the sum of the three sides subtract each side separately; multiply the half sum and three remainders together, and extract the square root of the product.*

PROBLEMS.

1. Base equals 4.75 ft.; altitude, 3.5 ft.; what is area? Ans. 8.312 sq. ft.

2. Base equals 2 ft. 7 in.; altitude, 2 ft. 5 in.; what is area? Ans. 3.12 sq. ft.

3. Sides equal 3 ft., 4 ft., and 5 ft.; what is area? Ans. 6 sq. ft.

4 Sides equal 1 ft. 10 in., 2 ft., and 3 ft. 2 in.; what is area? Ans. 1 sq. ft. 101.9 sq. in.

Parallelogram.

To find area when base and altitude are given.

Rule.—*Multiply the base by the altitude.*

PROBLEMS.

1. Base equals 9 ft. 4 in.; altitude, 2 ft. 5 in.; what is area? Ans. 22.5 sq. ft.

2 Base equals 2 yds. 2.25 ft.; altitude 5 ft. 9 in.; what is area in square feet? Ans. 47.4375 sq. ft.

Trapezoid.

To find area when parallel sides and perpendicular distance between them are given.

Rule— *Multiply half the sum of parallel sides by the perpendicular distance.*

PROBLEMS.

1. Parallel sides equal 2.25 ft. and 2.75 ft.; perp. dist., 2.5 ft.; what is area? Ans. 6.25 sq. ft.

2. Parallel sides equal 3 ft. 5 in., and 2 ft. 7 in.; perp. dist. 2 ft. 8 in.; what is area? Ans. 8 sq. ft.

Circle.

I.—To find area when diameter and circumference are given.

Rule.—*Multiply the diameter by one-fourth of the circumference.*

II.—To find area when the diameter is given.

Rule.—*Multiply the square of the diameter by .7854.*

III.—To find area when the radius is given.

Rule.—*Multiply the square of the radius by 3.1416.*

PROBLEMS.

1. Diameter equals $22\frac{1}{4}$ ft., circumference 69.9 ft.; what is area? Ans. 388.82 sq. ft.

2. Diameter equals 2 ft. 5 in., circumference 7 ft. 7 in.; what is area? Ans. 4 sq. ft. 83.75 sq. in.

3. Diameter equals 3.2 inches; what is the area? Ans. 8.042 sq. in.

4. Diameter equals 1 ft. 3 in.; what is the area? Ans. 1.227 sq. ft.

5 Radius equals 5 in.; what is the area? Ans. 78.54 sq. in.

6. Radius equals 2.25 in.; what is the area? Ans. 15.9 sq. in.

Convex Surface, Right Prism, or Cylinder.

To find area when perimeter of base and altitude are given.

Rule.—*Multiply perimeter of base by the altitude.*

PROBLEMS.

1. The sides of base of a right prism equal $5\frac{1}{4}$, $6\frac{1}{2}$, $8\frac{3}{4}$, 9, and 10 in., the altitude $11\frac{1}{4}$ in.; what is area of convex surface? Ans. 3 sq. ft. 12.375 sq. in.

2. The diameter of a right cylinder equals 1 ft. $2\frac{1}{2}$ in., the altitude 1 ft. 9 in.; what is area of convex surface? Ans. 6 sq. ft. 92.6 sq. in.

Convex Surface, Right Pyramid, or Cone.

To find area when perimeter of base and slant height are given.

Rule.—*Multiply sum of perimeter of bases by one-half the slant height.*

PROBLEMS.

1. Each side of a triangular pyramid equals 3 ft. 6 in., the slant height 18 ft.; what is area of convex surface? Ans. 94.5 sq. ft.

2. The diameter of the base of a conical tent equals 16 ft., the altitude 14 ft.; how many square yards of canvas in the tent? Ans. 45.016 sq. yds.

Convex Surface, Frustum, Right Pyramid, or Cone.

To find area when perimeters of bases and slant height are given.

Rule.—*Multiply sum of perimeters of bases by one-half the slant height.*

PROBLEMS.

Each side of lower base of a frustum of a quadrangular pyramid equals 10 in., of upper base 9 in., the slant height 20 in.; what is area of convex surface? Ans. 5 sq. ft. 40 sq. in.

2. The circumferences of the bases of a frustum of a right cone are 22 in. and 15.71 in., the slant height 26 in.; what is area of convex surface? Ans. 3 sq. ft. 58.23 sq. in.

Surface of Sphere.

The surface of a sphere equals four great circles.

To find area when diameter is given.

Rule.—*Multiply the square of the diameter by 3.1416.*

PROBLEMS.

Diameter of sphere equals 10 in.; what is area of surface? Ans. 314.16 sq. in.

2. Diameter of sphere equals 1 ft. 3 in.; what is area of surface? Ans. 4.91 sq. ft.

Volumes.

Prism or Cylinder.

To find volume when area of base and altitude are given.

Rule.—*Multiply the area of the base by the altitude.*

PROBLEMS.

1. The edges of the base of a rectangular prism equal 2.2 in. and 1.1 in., the altitude 3.3 in.; what is the volume? Ans. 7.986 cu. in.

2. The edges of the base of a triangular prism equal 3 ft., 4 ft., and 5 ft., the altitude 10 ft.; what is the volume? Ans. 60 cu. ft.

3. The diameter of base of a cylinder equals 1 ft. 3 in., the altitude 2 ft. 6 in.; what is the volume? Ans. 3.067 cu. ft.

4. The circumference of the base of a cylinder equals 3.1416 ft., the altitude 3 ft. 9 in.; what is the volume? Ans. 2.945 cu. ft.

Right Pyramid or Cone.

To find volume when area of base and altitude are given.

Rule.—*Multiply the area of the base by one-third of the altitude.*

PROBLEMS.

1. Each edge of the base of a right rectangular pyramid equals 2.5 ft., the altitude 2.25 ft.; what is the volume? Ans. 4.6875 cu. ft.

2. The radius of the base of a cone equals 5 ft., the altitude 21 ft.; what is the volume? Ans. 549.78 cu. ft.

Frustum, Right Pyramid, or Cone.

To find volume when area of bases and altitude are given.

Rule.—*To the sum of the two bases add the square root of their product, and multiply the result by one-third of the altitude.*

PROBLEMS.

1. Each edge of the lower base of a frustum of a right quadrangular pyramid equals 3 ft., of the upper base 2 ft., the altitude 15 ft.; what is the volume? Ans. 95 cu. ft.

2. The diameters of the bases of a frustum of a cone equal 18 in. and 10 in., the altitude 16 in., what is the volume? Ans. 2,530.03 cu. in.

Sphere.

To find volume when diameter is given.

Rule.—*Multiply the cube of the diameter by .5236.*

PROBLEMS.

1. The diameter of a sphere equals 10 in.; what is the volume? Ans. 523.6 cu. in.

2. The diameter of a sphere equals 15 in.; what is the volume? Ans. 1.0227 cu. ft.

CHAPTER XI

ALGEBRAIC EXPRESSIONS AND SIMPLE EQUATIONS

Algebraic Expressions.

An *algebraic expression* is a mathematical statement in which the *quantities* considered are represented *by letters* and the *operations* to be performed are indicated *by signs.*

The *quantities* may be either *known* or *unknown. Known quantities* are usually represented by the first letters of an alphabet; as $a, b, c; a', b', c'$, read "*a prime, b prime, c prime*"; a'', b'', c'', read "*a second, b second, c second*"; a_1, b_1, c_1, read "*a sub one, b sub one, c sub one,*" etc. *Unknown quantities* are usually represented by the last letters of an alphabet; as $x, y, z; x', y', z'; x_1, y_1, z_1; x_0, y_0, z_0$, read "*x sub zero, y sub zero, z sub zero,*" etc.

The *signs* are the same as those used in arithmetic.

Quantities multiplied together are called *factors* of their product. When factors are letters, the *sign of multiplication is omitted;* as $a \times b \times c$ is written abc; $\frac{a}{b} \times \frac{c}{d}$ is written $\frac{ac}{bd}$; $a \times a \times a \times a \times b \times b \times b \times c \times c \times d$, is written $a^4b^3c^2d$ and is read "*a fourth, b cube, c square, d.*"

A *coefficient* is usually a *number* written before a quantity expressed by letters to show how many times the quantity is to be taken additively. Thus: in $24ab$, 24 is the coefficient of ab, and shows that ab is taken, additively, 24 times.

When the quantity expressed by letters represents both *known* and *unknown* quantities, the product of the numerical coefficient and letters representing the known quantities is usually considered as the coefficient. Thus: in $7ax$, $7a$ is regarded as the coefficient of x or 7 may be regarded as the coefficient of ax.

When no coefficient is expressed, the coefficient 1 is always understood. Thus: abc means the same as $1abc$.

A *term* is an algebraic expression whose parts are not separated by a *plus* or a *minus* sign. Thus: $3ax$, $5by$, and $3ax \div 5by$ are terms. In $2x^2-3ax+4c^2$, $2x^2-3ax$, and $+4c^2$, are, respectively, the 1st, 2d, and 3d terms.

Terms in algebraic expressions, like numbers in arithmetic, are divided into *positive terms*, or terms to be added together, and *negative terms*, or terms to be subtracted from positive terms, but *added* to negative terms. *Positive terms* are preceded by the sign $+$; *negative terms* by the sign $-$. When a term has no sign before it, it is considered *positive*.

Like terms are terms which contain the *same letters* affected with the same *exponents*. Thus: $7a^2x^3$ and $-5a^2x^3$ are like terms. When positive and negative like terms are combined, the result is called their *algebraic sum*.

Thus: $2a^2x^3$ is the *algebraic sum* of $7a^2x^3$ and $-5a^2x^3$.

Equal terms are like terms that have the same numerical coefficient. Thus: $7a^2x^3$ and $-7a^2x^3$ are equal terms with unlike signs. When positive and negative equal terms occur in the same expression, they neutralize each other, or *cancel*.

The *numerical value* of an algebraic expression is the result obtained by assigning a numerical value to each letter and performing the operations indicated. Thus, the numerical value of

$$4a+3bc-d^2,$$

when $a=1$, $b=2$, $c=3$, and $d=4$, is

$$4\times1+3\times2\times3-4\times4=4+18-16=6.$$

PROBLEMS.

Find the numerical value of the following expressions, when $a=1$, $b=2$, $c=3$, and $d=4$.

1. $3a^2b^2-2(a+d+1)$. Ans. 0.

2. $\dfrac{a+c}{2}\times(a+d)$. Ans. 10.

3. $\dfrac{ab^4-c-a^3}{6}\times\dfrac{4a^2-b+d^3}{33}$. Ans. 4.

Of the following,

when $a=4$, $b=3$, $c=2$, and $d=1$:

4. $\dfrac{a}{2}-\dfrac{b}{3}+c-d$. Ans. 2.

5. $5\left(\dfrac{ab}{3}-\dfrac{a-a}{3}\right)$. Ans. 15.

6. $3[(a^2b+1)d]\div(a^2b+d)$. Ans. 3.

Of the following,

when $v=1{,}435$, $p=13.08$, $d=8$, $w=290$;

also, when $v=1{,}335$, $p=16.25$, $d=12$, $w=800$:

7. $v-608.3\{p+0.14d)\sqrt{\dfrac{d}{w}}\}$. Ans. approximately 0 and .8.

In dealing with the more simple algebraic expressions, the following rules apply:

Addition.

Case I.—When the quantities to be added are like terms.

Rule.—*Add the coefficients of the positive and negative terms separately; subtract the less sum from the greater, prefixing the sign of the greater; to the result annex the common literal part.*

CASE II.—WHEN ALL THE QUANTITIES TO BE ADDED ARE NOT LIKE TERMS.

RULE.—*Write the quantities to be added so that like terms shall fall in the same column; add each column separately, annexing unlike terms with their proper signs.*

PROBLEM.

Add $3a^2-2b^2-4ab$, $5a^2-b^2+2ab$, and $3ab-3c^2-2b^2$.

$$\begin{array}{rl} \textit{Solution:} & 3a^2-4ab-2b^2 \\ & 5a^2+2ab-b^2 \\ & \underline{\quad\quad +3ab-2b^2-3c^2.} \\ \text{Algebraic sum,} & 8a^2+ab-5b^2-3c^2, \quad \text{Ans.} \end{array}$$

SUBTRACTION.

RULE.—*Change the sign of each term of the subtrahend, or conceive it to be changed, and then proceed as in addition.*

When positive and negative terms are thus subtracted, the result is called their *algebraic difference.*

PROBLEM.

From $4a^2bx+acx+3ab^2+c^2$ subtract $a^2bx-acx+4ab^2-d$.

$$\begin{array}{rl} \textit{Solution:}\ \text{Minuend,} & 4a^2bx+acx+3ab^2+c \\ \text{Subtrahend,} & \underline{a^2bx-acx+4ab^2 \quad -d} \\ \text{Algebraic difference,} & 3a^2bx+2acx-ab^2+c+d, \quad \text{Ans.} \end{array}$$

Use of the parentheses.—When the sign $+$ is before parentheses, *the parentheses may be omitted.* Thus: $a+(b+c-d)=a+b+c-d$.

When the sign $-$ is before parentheses, the parentheses may be omitted, *if the sign of every term within the parentheses be changed.* Thus: $a-(b-c)=a-b+c$; $6a^2-(3ab+2c^2)=6a^2-3ab-2c^2$.

Any number of successive parentheses or brackets may be removed by these rules by omitting *first the innermost parentheses*, then the next innermost, and so on.

Conversely, any number of terms of an expression may be put in parentheses, and the sign $+$ placed before the whole; or the sign $-$ may be placed before the whole, *provided the sign of every term included in the parentheses be changed.*

Multiplication.

To multiply one term by another.

Rule.—*Multiply the coefficients together for a new coefficient; after this product, write all the letters in both terms, giving to each letter an exponent equal to the sum of its exponents in the two terms, or factors.*

If the terms have like signs, the sign of the product will be $+$; if unlike, it will be $-$. Thus: $abx \times ab^2x = a^2b^3x^2$; $-abx \times 2a^2bx^2 = -2a^3b^2x^3$; $(-ax) \times (-2acx) = 2a^2cx^2$.

In finding the *continued product* of several terms, if the *number of negative terms* is *even*, the product will be *positive;* if *odd*, the product will be *negative.*

When one of the factors is composed of more than one term, each term must be multiplied by the other factor, and the results connected by their proper signs. Thus: $(acx - a^2bx + 2x) \times (-3a) = -3a^2cx + 3a^3bx - 6ax$.

Division.

To divide one term by another.

Rule.—*Divide the coefficient of the dividend by that of the divisor for a new coefficient; after the new coefficient write all the letters of the dividend, giving to each letter an exponent equal to its exponent in the dividend minus that in the divisor.*

If the dividend and divisor have *like signs*, the quotient will be *positive;* if *unlike*, it will be *negative.* Thus: $4a^2bx^2 \div 2ab = 2ax$; $6a^2bx \div (-3ax) = -2ab$; $(-4ab) \div (-2b) = 2a$.

If the dividend contain several terms, and the divisor but one, each term of the dividend must be divided as above, and the results connected by their proper signs. Thus: $(6a^2-2abx+9ax)\div 3a=2a-\frac{2}{3}bx+3x$.

In the division of single terms, when the coefficient of the quotient is a *whole number* and the exponents of all the letters that enter it are *positive*, the division is *exact*.

In all other cases the quotient is essentially fractional, and the division is *inexact*. In such cases, all factors common to both dividend and divisor should be *canceled*, and the division of the other factors *indicated*. Thus:

$$\frac{12a^8b^6c^7}{16a^7b^6c^9}=\frac{3a\times 4a^7b^6c^7}{4c^2\times 4a^7b^6c^7}=\frac{3a}{4c^2}=\tfrac{3}{4}ac^{-2};$$

in which the exponent of b has been reduced to *zero*, and that of c is *negative*.

Zero power and negative exponents.—Let the powers of any *positive* quantity represented by a be arranged in a decreasing order. Thus: a^5, a^4, a^3, a^2, a^1.

From this it is evident that *the subtraction of 1 from the exponent of any quantity is equivalent to dividing the quantity by itself.*

If the subtraction be continued, the result will be a^5, a^4, a^3, a^2, a^1, a^0, a^{-1}, a^{-2}, a^{-3}, and so on.

Then, from the principle just stated, $a^0=a^1\div a=\frac{a}{a}=1$; $a^{-1}=a^0\div a=1\div a=\frac{1}{a}$; $a^{-2}=a^{-1}\div a=\frac{1}{a}\div a=\frac{1}{a^2}$; $a^{-3}=a^{-2}\div a=\frac{1}{a^2}\div a=\frac{1}{a^3}$; and so on.

Whence it appears that *any quantity with a zero exponent, or raised to the zero power, is equal to 1;* and that *any quantity with a negative exponent is equal to 1 divided by the quantity with an equal positive exponent.*

1 divided by a quantity is called the *reciprocal* of the quantity.

SIMPLE EQUATIONS.

An *equation* is a statement of the equality of two expressions. It is composed of two parts called *members,* connected by the sign of *equality;* the part on the left of the sign is called the *1st member,* that on the right the *2d member.* Thus: $x+a=b-c$ is an equation; $x+a$ is the 1st member, $b-c$ the 2d member.

Equations containing but *one* unknown quantity are divided into different *degrees,* or *orders,* according to the highest power of the unknown quantity found in any term. Thus:

$2x-3=9$, is an equation of the *1st degree.*
$2x^2-3x=9$ is an equation of the *2d* degree.

A *simple equation* is an equation of the *1st degree.*

The *root* of a simple equation is the value which will make its members equal when substituted for the unknown quantity. Thus: 6 is the root of $2x-3=9$.

To solve a simple equation is to find its root. The operations required in solving equations depend upon the following general principles:

1. *Both members of an equation may be increased or diminished by the same quantity without destroying the equality.*

2. *Both members of an equation may be multiplied or divided by the same quantity without destroying the equality.*

These principles are derived from the self-evident truth that—

If the same operation be performed upon equal quantities the results will be equal.

The two principal operations employed in solving simple equations are *transposing* and *clearing of fractions.*

Transposing is changing a term from one member to the other. *Any term may be transposed if its sign be changed.* For, in this operation, the same quantity is added to or subtracted from each member of the equation.

The signs of all the terms of each member may be changed, for this is in effect multiplying each term of both members by the same quantity, -1.

Clearing of fractions is reducing the terms of a simple equation to a common denominator and then multiplying every term by this denominator, or, what amounts to the same thing, omitting the denominator.

To clear an equation of fractions.—*Multiply each numerator by the denominators of all the other fractions, and omit the denominators.*

If any fraction whose *numerator* consists of *more than one term* is preceded by a *minus* sign, care must be taken to *change the sign of every term of the numerator* when the denominator is omitted. Mistakes may often be avoided by inclosing the numerator in parentheses before omitting the denominator; then, after omitting denominator, changing the sign of every term in the parentheses and omitting the latter.

To solve a simple equation.

Rule.—*Clear the equation of fractions and perform all operations indicated; transpose all terms containing the unknown quantity to the first member, all others to the second, and combine like terms; separate the first member into two factors, one of which shall be the unknown quantity, the other the algebraic sum of its coefficients; divide both members by the coefficient of the unknown quantity; the second member of the resulting equation will be the required root.*

The result may be verified by substituting the root found in the given equation. If it makes the two members equal, the result is correct.

PROBLEMS.

Solve the following equations:

1. $$\frac{a+1}{2}x-c=x-\frac{a+bc}{b}.$$

Clearing of fractions,

$$b(a+1)x-2bc=2bx-2(a+bc);$$

performing multiplications indicated and omitting parentheses,

$$abx+bx-2bc=2bx-2a-2bc$$

transposing,

$$abx+bx-2bx=-2a-2bc+2bc;$$

combining like terms,

$$abx-bx=-2a;$$

factoring the first member,

$$(ab-b)x=-2a;$$

dividing by coefficient of x,

$$x=\frac{-2a}{ab-b}, \quad \text{Ans.}$$

2. $x+18=3x-5$. Ans. $x=11\frac{1}{2}$.

3. $3ax+\frac{a}{2}-3=bx-a$. Ans. $x=\frac{6-3a}{6a-2b}$.

4. $\frac{x-3}{2}+\frac{x}{3}=20-\frac{x-19}{2}$. Ans. $x=23\frac{1}{4}$.

5. $\frac{x+3}{2}+\frac{x}{3}=4-\frac{x-5}{4}$. Ans. $x=3\frac{6}{13}$.

6. $2x-\frac{4x-2}{5}=\frac{3x-1}{2}$. Ans. $x=3$.

7. $3x-\frac{bx-d}{3}=x+a$. Ans. $x=\frac{3a-d}{6-b}$.

8. $\frac{ax-b}{4}+\frac{a}{3}=\frac{bx}{2}-\frac{bx-a}{3}$. Ans. $x=\frac{3b}{3a-2b}$.

PART II

GUNPOWDER AND HIGH EXPLOSIVES

Taken from Artillery Circular B, 1902

GUNPOWDER AND HIGH EXPLOSIVES

CHAPTER I

COMBUSTION, EXPLOSION, DETONATION

Ordinary Combustion.—In all explosions, the changes that occur may be considered the direct results of ordinary combustion, the manifestations of which, such as heat, light, etc., are universally known.

In their relation to combustion, all substances may be classified, first, as *combustibles*, or substances which burn, e. g., wood, coal, fats, oils, gas, etc.; and *incombustibles*, or substances which do not burn, e. g., glass, porcelain, earthenware, granite, etc.; secondly, as *supporters of combustion*, or those substances which aid or sustain combustion, e. g., air, oxygen (a gas), etc.;[1] and *non-supporters of combustion*, or those substances which retard combustion, e. g., nitrogen (a gas), etc.

In order that combustion may occur, or a substance burn, a combustible and a supporter of combustion must be brought together, and the temperature of the combustible raised to a point at which it may unite with the supporter of combustion.[2]

The temperature at which a combustible begins to burn

[1] The most energetic supporter of combustion is oxygen (a colorless, odorless, transparent gas). Air, the most common supporter of ordinary combustion, is such only by reason of the oxygen it contains, air being composed of 23 parts of oxygen and 77 parts of nitrogen (approximately).

[2] What actually occurs is, the elements of which the combustible is composed unite chemically with the oxygen of the supporter of combustion, forming new and entirely different products. This disintegration and union is generally brought about by the action of heat.

is called its "*point of ignition,*" and this point varies between very wide limits; thus, phosphorus ignites at 150° F., sulphur at 480° F., while several substances require a temperature over 1,000° F. for their ignition.

Combustion may be started, or a substance ignited in various ways; e. g., by contact with a heated body (such as a flame), by friction, percussion, concussion, an electric spark or current, etc.

The combustion of a substance may be promoted or increased by intimately mixing the combustible and supporter of combustion.

Thus, in order to kindle a fire rapidly, the wood is cut into small pieces or shavings. In the same way sawdust, if the particles be separated or suspended in the air so that they may be surrounded by or thoroughly mixed with it, burns far more energetically or intensely than the wood from which it was obtained.

The principal manifestations of combustion are *heat, light,* and *gas,* the first two being always perceptible to the senses, the latter being sometimes visible in the form of smoke, and at other times invisible.

Of these accompanying phenomena, the most important, from an explosive point of view, is the last mentioned, *gas,* and next in importance is the *heat* which causes the gas to expand.

Recapitulation.—1. Combustion is an example of chemical change, in which the combustible unites with the oxygen of the supporter of combustion.

2. In ordinary combustion the oxygen is supplied by the air.

3. The most energetic supporter of combustion is *pure oxygen.*

4. To ignite a combustible, or cause a substance to burn, its temperature must be raised to its point of ignition, and this may be done in various ways.

5. Combustion may be promoted or increased by intimately mixing the combustible and supporter of combustion.

6. The most important of the manifestations of ordinary combustion, from an explosive point of view, are *gas* and *heat*.

Very Rapid Combustion, or Explosion.—*Explosion* is generally defined as a *chemical change which results in the very rapid formation of a very great volume of highly expanded gas.*

As has already been stated, gas is one of the principal products of combustion, and it is also accompanied by heat, which causes the gas to expand, therefore the relation existing between combustion and explosion should be very close. As a matter of fact, such is the case, the only difference between the two phenomena being the length of time required to bring about the change. In other words, *combustion is only a slow form of explosion, or explosion a very rapid form of combustion.*

An explosive may be defined as *a substance or a mixture of substances which, when heated, struck, or subjected to the shock of another explosive, may result in the extremely rapid formation of a very great volume of highly heated gas.*

The first requisite, then, of an explosive is that it shall have sufficient oxygen to promote and sustain very rapid combustion. This supply of oxygen, not being found in the air, must be contained in the combustible elements of the explosive, or in other substances which are added for the purpose.

The principal substances thus used are potassium nitrate (India saltpeter, or niter), sodium nitrate (Chile or cubical saltpeter), potassium chlorate, nitric acid, etc. In these substances, which are called "*oxidizers*," or "*oxidizing agents*," the oxygen occurs in combination with other elements, and is liberated or set free in the form of gas by the action of external agents, such as heat, acids, etc.

A second requisite for an explosive which follows directly from the definition given is that the combustible element

and supporter of combustion (in this case the "oxidizer") shall be very intimately mixed so that the combustion may occur as far as possible in an atmosphere of oxygen. The combustibles previously mentioned (as well as the majority of others used in making explosives[1]) contain essentially carbon, hydrogen, and oxygen. At the moment of explosion (or combustion, depending upon the length of time occupied during the change) the carbon unites with a part of the oxygen to form gases called carbonic acid and carbonic oxide; the hydrogen unites with another part to form water in the form of steam, while any excess of oxygen is either set free as an elementary gas or unites with other elements that may be present.

While these gases themselves occupy a much greater volume than the original substance or substances from which they are obtained, still the *third requisite* of an explosive is found in the *heat* produced during the explosion, which serves to further expand these gaseous products.

Recapitulation.—1. Explosion is only a very rapid form of combustion.

2. The first requisite of an explosive is that it shall contain sufficient oxygen to promote and sustain energetic and very rapid combustion.

3. The oxygen may be contained in the combustible itself or supplied by other substances added for that purpose.

4. The second requisite of an explosive is that the products of explosion shall be chiefly *gaseous*.

5. These gases are formed by the union of the elements of the combustibles with the oxygen of the oxidizers added for that purpose, as well as to intensify the combustion.

6. The third requisite of an explosive is found in the *heat* produced during the explosion which serves to greatly expand the gases produced at the same time.

[1] Except sulphur, which unites with oxygen to form various products, solid and gaseous.

Instantaneous Combustion or Detonation.—*Detonation* may be defined as *the instantaneous combustion of the entire mass of the combustible,* and is therefore only an extremely rapid form of explosion.

Practically this definition is incorrect, since even in detonation there must always be some interval of time in order that the explosion may be propagated from one particle of the explosive to another. The rate or velocity of detonation has been determined for some substances; e. g., that for dry compressed guncotton has been found to be from 17,000 to 18,000 feet per second, or about 200 miles per minute.

From the relation existing between combustion, explosion, and detonation, the first requisite of a detonating substance is that the union between the combustible and supporter of combustion shall be the closest possible.

In the case of *exploding substances,* or those explosives which under normal conditions *merely explode,* the combustible and oxidizer are mixed *mechanically.* Thus, in gunpowder the charcoal, sulphur, and niter are separately pulverized, and then mixed as thoroughly as possible by proper machines.

This degree of incorporation, or mixing, is not sufficiently intimate in the case of detonating substances, and in order to secure the closest possible union of the necessary elements, they are mixed *chemically.* Thus, in the case of nitroglycerin, when glycerin is poured slowly into nitric acid, the latter acts upon the former *chemically,* and forms an entirely new *compound substance,* in which the elements are in the closest possible union.

Explosive Mixtures and Explosive Compounds.—From the different manner in which the elements of explosive substances are united results the most important division in the classification of explosives, viz.:

Explosive mixtures are *those explosive substances* in which the elements or *ingredients are mixed mechanically, and may be separated by mechanical means.*

Explosive compounds are *those explosive substances in which the elements or ingredients are united chemically, and can be separated only by chemical means.*

From what has just preceded, the natural deduction is that explosive mixtures "explode," while explosive compounds "detonate," and such may be considered the normal action of these two classes of explosives.[1]

However, under certain conditions, their relative actions may be reversed, while explosives of both classes, if ignited in small quantities and unconfined generally, burn away harmlessly.[2]

Methods Employed to Cause Explosives to Explode.—As in the case of combustibles the point of ignition varies with each substance, so, with explosive mixtures, each has its "*exploding point*," to or beyond which its temperature must be raised in order to produce explosion. With explosive compounds, however, detonation can with certainty be produced only by an initial explosion of *fulminate of mercury*, or by that of a second detonating substance. This peculiarity in the action of explosive compounds is explained by the theory that when fulminate of mercury is exploded it sets up a vibratory motion to which detonating substances are particularly susceptible, and which causes their instantaneous disintegration.

The more usual methods practically employed to cause explosives to explode are:

1. *Ignition*, as when gunpowder is fired by means of a wire heated by the passage through it of an electric current.

2. *Inflammation*, as when gunpowder is fired by the flame produced by the ignition of a fuse.

[1]According to their mode of action, explosives are sometimes classified as "low explosives," or those which explode, and "high explosives," or those which detonate.

[2]As used in smokeless powders, the action of explosive compounds is so regulated as to eliminate the possibility of detonation. This result in the case of nitrocellulose powders is accomplished by the process of "colloiding."

3. *Percussion,* as in the firing of percussion caps and metallic caps and metallic cartridges in small arms.

4. *Friction,* as seen in the use of ordinary friction primer.

5. *Detonation,* as when fulminate of mercury is used in blasting caps, torpedo detonators, etc.

Recapitulation.—1. In detonation the time required to accomplish the change is reduced to a minimum, and the combustion (or explosion) may be considered practically *instantaneous.*

2. *Detonating substances* are *chemical compounds,* in which each minutest particle contains in itself all the necessary elements for its combustion (or explosion).

3. *Explosive mixtures* are those explosive substances in which the elements or ingredients are mixed *mechanically.*

4. *Explosive compounds* are those explosive substances in which the elements or ingredients are united chemically.

5. Under normal conditions explosive mixtures explode, while explosive compounds detonate.

6. The more usual methods of causing explosion are ignition, inflammation, percussion, friction and detonation.

CHAPTER II

EXPLOSIVE MIXTURES—GUNPOWDER

Gunpowder.[1]—Gunpowder may be taken as a representative explosive mixture. It is a very intimate mixture of potassium nitrate (saltpeter or niter), sulphur, and charcoal. Although these substances do not act upon each other at the ordinary temperature, when thoroughly mixed and heated they are momentarily dissociated (separated), the elements immediately rearranging themselves as new products which are largely in the form of highly heated gas.

Ingredients of Gunpowder.—The ingredients of gunpowder are easily obtained and in large quantities, saltpeter and sulphur occurring naturally, the one mixed in the soil of certain countries, notably India, the other in caves and the vicinity of volcanoes, while charcoal is merely the residue of charred wood.

Proportions of the Ingredients.—The three ingredients of gunpowder may be mixed in greatly varying proportions and each mixture will be explosive, but, for ordinary service gunpowder, experience has shown that a powder containing—

Saltpeter	75 parts
Sulphur	10 parts
Charcoal	15 parts

is the best, and until recently the majority of military nations adopted it.

The large proportion of sulphur used in the earlier powders

[1] Gunpowder and its manufacture are described because certain of these powders are still retained in the service.

is no longer necessary since the introduction[1] of percussion caps, friction primers, etc.; and since when present in large quantities it introduces in the powder certain disadvantages, the percentage of sulphur in modern gunpowders is reduced as much as possible, being only from 2 to 3 per cent. in the *cocoa* powders, which are decidedly the best for guns of large caliber.

In order to secure uniform results and safety during the process of manufacture, the ingredients, before being mixed, are separately pulverized. The saltpeter, if used immediately after being purified, is sufficiently fine and requires no further reduction; but if it has been stored and become caked, it, like the sulphur, is ground to a very fine powder in a machine similar to an ordinary "mortar-mill." Because it is very porous and quickly absorbs moisture, the charcoal is not stored in large quantities or for any length of time, but is prepared about two weeks before it is required for use, when it is ground to powder in a machine resembling a large "coffee-mill," and then stored in air-tight metal boxes.

Manufacture of Gunpowder.—The ingredients are now ready for the manufacture of the powder, which consists of the following processes:

1. *Mixing the ingredients.*—A 50-pound charge is carefully weighed in the proper proportions and placed in a gun-metal or copper barrel (or *drum*), through the center of which passes an axle to which are attached several fork-shaped arms, also made of gun metal. When in operation the barrel and axle carrying the arms revolve in opposite directions, and at the end of five minutes the charge is thoroughly mixed.

2. *Incorporating or "milling."*—The charge is next uniformly spread in the "incorporating mill" and slightly moistened with

[1] In gunpowder, saltpeter acts as the oxidizer and charcoal as the combustible, while the sulphur was originally added to lower the point of ignition, although it also served to increase the amount of heat produced and to further expand the gases.

water,[1] and subjected to continued grinding under heavy rollers. The product is known as "mill-cake."

3. *Breaking down the "mill-cake."*—After removal from the incorporating mill, the mill-cake is "broken down," or reduced to "*powder meal,*" by being passed through two pairs of gun-metal toothed rollers.

4. *Pressing.*—The powder meal is next placed in the "press box," where it is compressed into hard slabs or sheets. Next to incorporation, pressing is the most important step in making gunpowder. The principal advantages obtained by pressing are: *first,* the slabs or sheets when made into grains of the required size absorb less moisture from the air; *second,* the lasting qualities of the powder are greatly increased; *third,* the powder is less liable to be reduced to powder in transportation; and, *finally,* it supplements the object sought in incorporating, inasmuch as by it the ingredients are brought into a closer union, thereby producing greater uniformity in the grain. The effect of *pressing* upon the *density* of the powder can not be overestimated and will be referred to again.

5. *Granulating.*—The slabs or sheets as they come from the press box are known as *press cake,* and are passed to the granulating machine, which is similar to the breaking-down machine, consisting essentially of three or four pairs of gun-metal toothed rollers, the size of the teeth of which vary according to the size of grain required.

6. *Dusting.*—The granulated powder is next passed through revolving reels covered with canvas cloth in which the dust formed during the last step is removed.

7. *Glazing.*—As a general rule, all modern military powders are *glazed.* This is done by introducing the charge of granulated powder in oaken barrels containing small quantities of graphite or plumbago (about one-half ounce of graphite to

[1] This is done for the threefold purpose of preventing powder-dust from flying about, facilitating the incorporation, and reducing the effects of an explosion in case of an accident.

one hundred pounds of powder), and causing the barrels to revolve rapidly. At the end of six hours the grains will have acquired a fine gloss, while all sharp angles and corners will have been rounded off.

The object of glazing is to diminish the formation of dust during transportation and to render the powder less *hygroscopic* (that is, less liable to absorb moisture from the air).

Properties of Gunpowder.—Good gunpowder should be composed of hard angular grains which do not soil the fingers when handled, and have a perfectly uniform dark-gray color. The grains when broken should present a clean fracture, homogeneous in appearance, without any visible specks of saltpeter or sulphur, and of a dark grayish or brownish color, according to the kind of charcoal used. When new it should be free from dust, and a small quantity flashed upon a porcelain or copper plate should leave no residue or foulness. It should not absorb more than from 0.5 to 1.5 per cent. of water when exposed to air of average dryness. The grains should be sufficiently hard to stand transportation without being broken.

The property which exercises the greatest influence upon the general character and action of gunpowder is its *density*,[1] which should vary between the limits of 1.60 and 1.85 according to the kind of powder.

Density must not be confounded with hardness, which seems to bear a direct relation to the pressure exerted in compression ("pressing"). Although a *very high* density can not be obtained without producing a considerable degree of hardness, still a powder may be very hard without being very dense: For example, "powder meal" containing 6 per cent. of water can be made very dense by the application of a moderate pressure, while that containing 1 per cent. of water can be brought to the same degree of density only by the exertion

[1] Density is the ratio which the weight of a given volume of the substance (in this case, powder) bears to the weight of an equal volume of distilled water at 60° F.

of enormous force. Of the resulting powders the latter will be the harder.

No experimental proof is necessary to show that if two grains of powder of equal size, one of which is twice as dense as the other, be ignited in the open air the denser will take longer to burn completely; for the former not only has a closer and less porous texture of grain, but contains, bulk for bulk, a larger amount of matter to be burned from the same surface.

It is evident, therefore, that the *density* of the powder, which can be varied at will, must be its *most important physical quality*, or property.

Recapitulation.—Gunpowder may be taken as the representative of the explosive mixtures, and consists of saltpeter (niter), sulphur, and charcoal.

The several steps in the manufacture of gunpowder and their objects are:

(1) Mixing the ingredients.
(2) Incorporating the ingredients, to bring the pulverized ingredients into such intimate contact that each particle of the powder shall contain, if possible, a particle of each ingredient.
(3) Breaking down the "mill-cake," so that it can be introduced into the press box.
(4) Pressing, to give strength and density[1] to the powder.
(5) Granulating, to regulate the surface of combustion.
(6) Dusting, to prevent the absorption of moisture, and to insure uniformity of combustion.
(7) Glazing, to diminish the formation of dust during transportation, and also to protect the grains from the action of the moisture of the air.

Of the properties of gunpowder enumerated, the most important are its density and that of being able to resist the action of the moisture of the air.

[1] The density is also affected by the kind of charcoal used and the amount of water used to moisten the ingredients before being introduced into the press box.

CHAPTER III

GUNPOWDER—Continued

The processes described in the preceding chapter refer particularly to the manufacture of powders the sizes of the grains of which do not exceed in diameter ¼ inch. When a charge of such powder is burned in the bore of a gun the flame rushes rapidly through the spaces between the grains, causing very rapid combustion and correspondingly rapid formation of gas.

With ordinary cannon powder it has been found that *seven-eighths* of the entire charge is consumed before the shot passes over *one-third* the length of the bore; this action of the powder causes excessive pressures at or near the base of the bore of the gun, due to the fact that the evolution of gas is greatest while the velocity of the projectile is least.

Special Powders.—Experiment has shown, however, that the amount of gas evolved at the first instant of inflammation and the combustion of the charge can be measurably controlled by the size and form of the grain and the density of the powder. The first two conditions regulate the *area* of surface exposed to combustion, while by increasing the density of the powder greater resistance is offered to the penetration of the hot gases through the grains, and the rapidity of burning is thereby controlled.

These principles are now so universally recognized that special powders differing in these features are manufactured for use in guns of different calibers in order to secure the best results. Such powders are called *special powders*. The forms of grain adopted for such powders are regular geometrical

figures, such as *hexagons, cubes,* and *prisms,* the resulting powders being known as *hexagonal, cubical* (or pebble in England, where this form is used), and *prismatic.*

Hexagonal Powder.—This powder is still retained in the United States Army for use in certain old guns. Each grain is formed of two truncated six-sided pyramids, which are united base to base, the plane of union being therefore a hexagon. (See Fig. 1.) The uniform size and shape of the grain insure uniformity in position and size of the interstices in the cartridge; this insures uniformity in density of loadings which, with uniform density of the grains, produces uniform and low pressure, and uniform and high velocities.

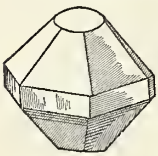


Fig. 1.

Manufacture of Hexagonal Powder.—The ingredients themselves, the proportions of the ingredients, and the processes of manufacture of hexagonal powder are similar in every respect to those already described up to the completion of the "mill-cake." The following modifications are peculiar to this powder:

Mealing.—The "mill-cake," broken with wooden or copper mallets, is revolved in a cylinder of wire-woven cloth with *wooden* balls until it is *mealed.*

Pressing.—The mealed powder is then moistened and carefully pressed between metallic plates containing dies which correspond to the truncated six-sided pyramids already described. The powder comes from this machine in polyhedral grains connected along their hexagonal edges.

Granulating.—The press cake is passed through rollers armed with teeth set at an angle of 120 degrees to the axis which separate the grains.

Glazing.—The powder is next glazed by being run into a glazing barrel containing highly glazed small-grained powder (rifle or mortar).

Brushing.—The powder is next passed repeatedly through

the brushing machine. This consists of a frame with brushes revolving near an inclined plane, along which the powder is made to pass by the motion of the brushes.

Drying.—The powder is next dried, and then carefully examined; its density and granulation determined, a difference of two grains (or granules) to the pound being enough to condemn the powder.

Rebrushing, Redrying, and Packing.—If the results of the preceding examination are satisfactory, the powder is again passed through the brushing machine, redried, brushed a third time, and then packed in barrels.

Prismatic Powders.—In selecting the original shape for special powders, several practical considerations led to the adoption of regular geometrical figures, one of the first experimented with being the *right hexagonal prism.* The earlier prismatic powders contained seven perforations (see Fig. 2) in the direction of the axis of the prism, one in the center, and one within each angle. It was soon discovered, however, that it was impossible to make the walls of the prisms sufficiently strong to resist the action of the heated gases rushing through the perforations, the result being that the prisms were broken up and reduced practically to fine-grain powder.

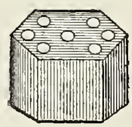


Fig. 2.

A single perforation was therefore substituted, and as thus modified the *perforated prismatic powders* were used by the majority of military nations of the world in all guns of large caliber. The best-known prismatic powder is the *brown* or *cocoa powder.* (See Fig. 3.) The characteristic color (brown) of this powder is derived from the charcoal used, which is slightly carbonized or charred rye straw, while the proportions of the ingredients are as follows:

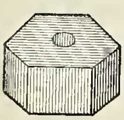


Fig. 3.

Saltpeter........................	80 parts.
Sulphur..........................	2 to 3 parts.
Charcoal.........................	18 to 17 parts.

The theory of this powder is that ignition occurs first in the interior of the grains (i. e., along the central perforation), and the combustion proceeds uniformly outward until the entire prism is consumed. By this action of the powder, which is rendered possible by the shape of the grain and the high and uniform density of the powder (1.86), the smallest surface of combustion is exposed to inflammation at the instant of ignition, when the velocity of the projectile is least, and constantly increases as the projectile moves down the bore and acquires its greatest velocity. The result is moderate and uniformly sustained pressures on the gun, with uniform and high initial velocities.[1]

Recapitulation.—1. Small-grain powders burn too rapidly and irregularly to be used in guns of large caliber.

2. *Special powders* burn more slowly and uniformly, so that excessive pressures on the gun are avoided, and more uniform and higher velocities are imparted to the projectile.

3. The perforated prismatic powders are the best special powders.

4. The granulation of prismatic powders is uniform, and the rate of their combustion is regulated by varying the composition.

[1] The sizes of the grains of brown powder are practically uniform, being of the same dimensions for 8, 10, and 12-inch rifles. The rate of combustion of these powders is regulated by varying their composition, the rate decreasing as the caliber of the piece increases.

CHAPTER IV

SMOKELESS POWDERS

Although black and brown powders are still used to a very limited extent, all military powers have, within the last twenty years, adopted smokeless powder for use in guns of all calibers. Smokeless powders differ radically from ordinary gunpowders, both in composition and granulation. Although various substances have been experimented with, all military smokeless powders may be divided into two classes:

1. Those consisting of guncotton alone.
2. Those consisting of guncotton and nitroglycerin.

In the United States powders of the second class are used in small arms, rapid-fire, field, and siege guns, while those of the first class are used in all other guns.

Manufacture of Smokeless Powder.—The wet guncotton as it comes from the pulping machine is transferred to an apparatus called "dehydrator," which consists of a steel cylinder, one end of which is fitted with a perforated plate. A heavy solid-headed piston works longitudinally in the cylinder. The first action of the piston is to express the water contained in the guncotton. Alcohol is then poured into the dedydrator and forced through the guncotton until the alcohol runs from the dehydrator of the same strength as when introduced. Sufficient alcohol is allowed to remain in the guncotton to act as a solvent. The guncotton is removed from the dehydrator in the form of a moist cake, is broken up, put into the "mixer," and the requisite amount of ether added to thoroughly dissolve the guncotton. In powders of the second class acetone is used as the solvent instead of alcohol and

ether, and the nitroglycerin is dissolved in a part of the acetone before it is added so as to reduce its sensitiveness.

The ingredients and solvent having been placed in the "mixer," the workmen withdraw from the building, and the process of incorporation is begun. It requires from one to two hours to effect thorough incorporation, at the end of which time the powder appears as a pasty mass. The powder is next compressed into a solid cake preparatory to passing through the graining press. Until recently the paste was rolled into sheets of varying thickness by passing it between steam-heated rollers, and the finished powder is still frequently seen in this form.

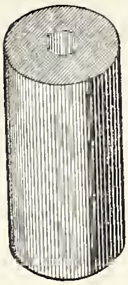


Fig. 4.

The sheets of powder are placed in a drying house, where the bulk of the remaining solvent is driven off, when they are again rolled to eliminate the "blisters" formed by the escape of the solvent from the interior of the sheets, as well as to perfect the incorporation.

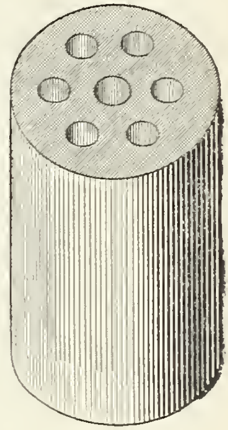


Fig. 5.

In case of the "*flake, sheet,*" or "*strip*" powders, as the powder comes from the rolling machine, it is of the consistency of india-rubber and the thinner sheets or strips are perfectly translucent.

Recently the perforated cylindrical grain, either single or multiperforated (see Figs. 4 and 5), has almost entirely superseded the earlier forms of flake and strip powder.

In making the cylindrical-grained powders, the paste is placed in a large cylinder (made of cast iron or steel), which has a piston entering through its head. The piston is generally actuated by hydraulic power, and serves first to compress the paste and then to force it through a die attached to the base of the press.

To prevent clogging of the dies the paste is first forced through a plate perforated with very fine holes.

By varying the diameter (or form) of the die the same press may be used for pressing and molding powders for use in guns of all calibers.

In case of powders of small diameters, such as *filite, cordite,* etc., the thread or cord is either reeled at once, as it emerges from the press, on drums, and the drums are then transferred to the drying house, where they remain until practically all of the solvent is driven off; or it is received on a canvas belt which passes over steam-heated pipes and is discharged into wire baskets, which are subsequently placed in the drying house until the cord or thread is ready for granulation. For small-arm powder the threads are passed under revolving knives and cut into very short cylinders, which are dusted and sometimes glazed as described in the case of ordinary gunpowder. The diameters of powders intended for guns of larger caliber vary according to the gun, and the grains are both perforated and cut into lengths as the powder emerges from the dies.

Properties of Smokeless Powders.—The color of smokeless powder varies from a grayish yellow to dark brown, and from being translucent to entire opaqueness. When glazed they resemble ordinary gunpowder, except in form of grain, but upon cutting through the grain or washing off the graphite the color peculiar to the composition of the powder is readily seen. In texture they are smooth, and are either very hard and brittle or they are tough and of the consistency of india-rubber. They are insoluble in water and are practically unaffected by it. They are insensitive to shock of impact or to the passage of a bullet through them. They are more difficult to ignite than black powder and charges are generally primed with the latter to insure ignition. They leave very little residue in the bore of a gun.

Recapitulation.—1. Smokeless powders may be divided into two classes, viz:

(1) Those consisting of guncotton alone.
(2) Those consisting of guncotton and nitroglycerin.

2. In both classes of smokeless powders the guncotton is dissolved[1] and reduced to a gelatinized mass and then pressed into grains of regular shape.

3. The form of grain adopted by the United States is a cylinder which for guns of small caliber has but one central perforation, while the grains for guns of larger caliber are multiperforated.

4. Smokeless powders differ radically from ordinary gunpowder in physical properties as well as in their composition.

[1] The substance formed by dissolving guncotton is technically called a "*colloid.*" *Colloids* when ignited even in a closed chamber do not explode, but burn regularly in parallel surfaces. It is this property of colloids that renders them available for use in guns.

CHAPTER V

EXPLOSIVE COMPOUNDS—GUNCOTTON AND NITROGLYCERIN

As gunpowder is the best-known example of explosive mixtures, so guncotton and nitroglycerin may be taken as the best known, and with their derivatives the most generally used types of explosive compounds.

Guncotton.—As its name implies, this is an explosive derived from cotton, and is made by dipping or steeping *pure dry cotton in a mixture of the purest and strongest nitric and sulphuric acids.*

The purification of the cotton before being immersed, the conversion of the cotton into guncotton, and the subsequent purification of the guncotton are lengthy processes attended with considerable difficulty, and requiring complicated machines, but the principles governing these steps are easily understood.

For practical reasons the cotton used in the manufacture of guncotton is "cop waste" (or "weaver's waste"), which consists of the tangled clippings from the spinning rooms of cotton-mills. It therefore generally contains more or less oil, dirt, and moisture (water). When impure or unclean cotton is immersed in the acid mixture, the impurities (oil, dirt, etc.) are acted upon by the acids and form compounds which are unstable and liable to explode during manufacture, and, if not removed, lead to the subsequent decomposition of the guncotton.

The presence of moisture during the immersion of the cotton serves to dilute the acid mixture and to cause heat,[1] which

[1] The heat is caused by the water uniting chemically with the sulphuric acid.

also gives rise to the formation of unstable compounds, whose action is as just described.

The use of weak acids or too short an immersion prevents the complete conversion of the cotton into the highest and most stable form of guncotton, such as is used for military purposes.[1]

Manufacture of Guncotton.—The following is an outline of the processes of manufacture of guncotton followed by the best factories in this country and abroad:

1. The "cop waste" is first thoroughly cleansed and dried.

2. The acids are mixed in the proportions of 1 part of nitric to 3 parts of sulphuric[2] and allowed to cool.

3. The cotton is immersed in the proportions of 1 part of cotton to 10 parts of acid for the period of ten minutes.

4. Nearly all of the acid is squeezed out of the guncotton, which is next placed in an earthenware crock and allowed to remain ("digest") for twenty-four hours.

5. All remaining traces of acid are removed by wringing, washing, and boiling the guncotton.

6. The guncotton is reduced to the fineness of corn meal in a machine similar to an ordinary paper-pulping machine.

7. The guncotton pulp is washed, first in fresh water, and then in water containing lime, caustic soda, and marble dust.[3]

8. The water is drawn off and the guncotton drained until

[1] When cotton is acted upon by mixtures of nitric and sulphuric acid various products are obtained, nearly all of which are more or less explosive and more or less stable, depending upon the strength of the acids and the length of time the cotton is subjected to their action. Only the highest grade of guncotton, obtained as described above, is sufficiently stable for military purposes. This product is called "trinitrocelluluse."

[2] The sulphuric acid is added to absorb any original moisture present in the waste or nitric acid, as well as the water formed during the conversion, so as to preserve the necessary strength of the nitric acid.

[3] This last solution is used to neutralize or destroy any possible trace of acid that might remain in the guncotton.

it contains about 30 per cent. of water, and in this condition is stored in large tanks until required for use.

9. As found in the service, guncotton is packed in bulk in boxes containing about 100 pounds, or in molded rectangular blocks 2.9 by 2.9 by 2 inches. The corners of the blocks are chamfered and each block is perforated through the center to receive a detonator.

Properties of Guncotton.—The fibrous[1] guncotton seen in ordinary light differs very little, if any, from the cotton from which it is made. It is harsher to the touch and less flexible than cotton; when dry, it becomes highly electrified if rubbed between the fingers, and is luminous when rubbed in the dark.

Guncotton is completely insoluble in water and is said to absorb less moisture from the air than either ordinary cotton or gunpowder.

The fibrous guncotton ordinarily contains from 1.5 to 2 per cent. of water when dry, and may absorb as much as 2.75 per cent. of moisture without having any of its properties impaired.

A molded block of guncotton as it comes from the press weighs about 10 ounces, and contains from 14 to 16 per cent. of water. Before being sent from the factory, the blocks are soaked in fresh water until they cease to absorb water,[2] and are packed directly in the torpedo cases.

If a flame or any incandescent body be brought into contact with dry, loose guncotton, the latter burns with a flash but without explosion. A block of compressed guncotton may be safely ignited in the hand, placed on the ground, and the flame extinguished by pouring water on it; but if a very large mass of guncotton be ignited, an explosion may result from the intense heat of the burning portion raising the

[1] Fibrous guncotton is the product before passing through the pulping machine and being cut up or reduced.

[2] They then contain about 35 per cent. of water, and can be exploded only by the detonation of dry blocks placed in contact with them.

temperature of the rest up to its point of explosion, while at the same time acting as a partial confinement to the unignited portion. The exploding point of guncotton is about 360° F.

To develop the force of guncotton it must be strongly confined when detonated, and unless so confined it is not particularly sensitive to friction, percussion, pressure or shock. Cold has no effect on guncotton unless sufficiently intense to freeze the water contained in it. The effect of freezing on wet compressed guncotton is to cause flaking, cracking, and breaking or crumbling of the block, which is to be avoided if possible. While guncotton is one of the most powerful explosives, and necessarily dangerous as all explosives are, when handled, stored, and used as directed, it is the safest explosive known, and is especially adapted for use for military purposes.

Decomposition of Guncotton.—When properly made guncotton is almost entirely free from any tendency to undergo dangerous decomposition. The decomposition (deterioration) of guncotton is caused primarily by the action of any free acid that may be present (in the product) due to imperfect washing of the product after conversion, or to the presence of impurities due to imperfect cleansing of the cotton before conversion or to incomplete conversion. The action of the acid is accelerated and intensified by *heat.*

When guncotton is decomposing it first begins to give off deep brownish-red fumes, and at the same time it begins to show pasty yellow spots, and eventually the whole becomes converted into a pasty yellow mass which first shrinks to about one-tenth of the volume of the original guncotton, and then swells up as the gas is evolved. During the next stage the guncotton again shrinks and is converted into a gummy residue, which finally dries up to a brown horn-like mass. Heat[1] is produced during decomposition, and if the

[1] This heat is due to chemical action.

guncotton is confined the heat generated may raise its temperature up to its exploding point and cause an explosion.

To produce this result in wet guncotton it is necessary that the amount of acid present should be very much in excess of the guncotton with which it is in contact, while the water present tends to prevent any considerable rise in temperature.

Nitroglycerin.—In its composition and structure glycerin is chemically analogous to cotton, and nitroglycerin is derived from the former in exactly the same manner that guncotton is obtained from the latter.

Nitroglycerin is an explosive compound made by acting upon *pure anhydrous*[1] *glycerin* with a mixture of the *purest and strongest nitric and sulphuric acids.*

The considerations which require absolutely pure and dry materials in the manufacture of guncotton apply with equal force in making nitroglycerin.[2]

Sobrero, the discoverer of nitroglycerin, proposed the following process for making this explosive: *"Pour ½ ounce of anhydrous glycerin, with constant stirring, into a mixture of 2 ounces of concentrated sulphuric acid, and 1 ounce of fuming nitric acid."*

Manufacture of Nitroglycerin.—The following is an outline of the manufacture of nitroglycerin by all large dynamite makers[3] in this country.

1. About 600 pounds of nitric acid and 1,100 pounds of sulphuric acid are mixed in a leaden tank and allowed to cool for twelve hours.

2. This mixture (about 1,700 pounds) is run into the

[1] A substance is said to be *anhydrous* when it is entirely free from moisture.

[2] It is the presence of fatty impurities in the glycerin that gives rise to the formation of unstable bodies, which cause the decomposition and so-called spontaneous explosion of nitroglycerin. The presence of water, or the use of weak acids, acts as described.

[3] This process is known as the "Mowbray method of making nitroglycerin," having been introduced into this country by Mr. Mowbray.

mixing apparatus,[1] and into it is *injected in the form of spray* the charge of glycerin (about 240 pounds).[2]

3. After the entire charge of glycerin has been introduced it is allowed to remain in the mixing apparatus for a few minutes, and the nitroglycerin which appears on the surface is then separated from the acid mixture.

4. The nitroglycerin is next thoroughly washed with fresh water until it shows no trace of acidity.

5. To neutralize (or destroy) the effect of any traces of acid which may not have been removed by the last washing, the explosive is next washed with a solution of carbonate of soda in water until it shows a distinct alkaline reaction.[3]

6. The nitroglycerin in transferred from the washing apparatus, through coarse muslin filters, to the storage tanks, where it is kept generally under water.

The *French method* of making nitroglycerin differs in principle from that just described. In this process two mixtures are made, one of equal parts of nitric and sulphuric acids, the other a mixture of 1 part of glycerin and about 3 parts of sulphuric acid.

Both mixtures are allowed to cool and are then mixed in the proportions of about $5\frac{1}{2}$ parts of the first to about 4 parts of the second and the conversion allowed to proceed by itself. About twelve hours are required for the complete conversion of 300 pounds of glycerin by this process.

[1] The mixing apparatus consists of a large cast-iron tank filled with water and containing a smaller iron tank in which the materials are mixed. The latter contains leaden "worms" (or spiral pipes) through which cold water is made to circulate during the mixing.

[2] This step is attended with the evolution of considerable heat, which, unless regulated, is liable to "fire" the charge. It is therefore necessary to watch a thermometer (the bulb of which is immersed in the mixture) carefully, and should the temperature rise above 80° F., the introduction of the glycerin is stopped.

[3] The presence of acid in a solution is shown by the color of *blue* litmus paper being changed to *red* when dipped in it. If a solution is alkaline, the color of *red* litmus paper is changed to *blue*.

Properties of Nitroglycerin.—Freshly made by the Mowbray process, nitroglycerin is a creamy white, opaque, oily liquid, but upon standing for a time, the length of which depends upon the temperature, it "clears" or becomes transparent and colorless, or nearly so. As found in commerce it has a yellow or brownish-yellow color. Although very slightly soluble in it, it does not mix with and is unaffected by cold water. It has a sweet, pungent, aromatic taste, and is an *active poison*, so that mere contact with it will induce in most persons a violent sickness, and an especially painful form of headache.[1] Freshly made opaque nitroglycerin freezes at about —4° F., and the transparent explosive at about 40° F., in both cases freezing to a white crystalline mass; and once frozen it remains in this condition even when exposed for some time to a temperature above its freezing-point.

Pure nitroglycerin is not sensitive to friction or moderate percussion, except when pinched between metallic surfaces.[2] When confined and struck a smart blow it explodes on account of its incompressibility; when in a state of decomposition, however, it is much more sensitive and explodes upon being struck even if unconfined.

The firing-point of nitroglycerin is about 356° F. Unconfined and freely exposed to a flame nitroglycerin burns with a brilliant flame, but without explosion. In a frozen state nitroglycerin becomes insensitive to nearly all kinds of shock, but at the same time loses in a great measure its explosive power, and it should therefore be thawed before being used.

Most of the accidents[3] that have occurred with nitrogly-

[1] Strong black coffee is recommended as an antidote.

[2] A quantity of nitroglycerin has been thrown up by means of a rocket to a height of 1,000 feet, whence it fell without explosion upon impact.

[3] One very frequent source of accident results from carelessly allowing cans or other vessels in which nitroglycerin has been stored to lie around loosely. In nearly every case particles of the explosive adhere to the vessels and are exploded by a chance blow. All such vessels should be destroyed immediately.

cerin have resulted from carelessness in thawing the explosive.

How to Thaw Nitroglycerin when Frozen.—When frozen, nitroglycerin may be conveniently and safely thawed by placing the vessel containing it in another vessel containing water not hotter than the hand can bear (about 100° F.) and allowing it to remain, replenishing the warm water when necessary, until the explosive is thawed. Under no circumstances should frozen nitroglycerin be put in the same vessel as the water, nor should it be placed near an open fire nor in contact with any heated surface, nor, in short, thawed in any other way than as just directed.

Decomposition of Nitroglycerin.—Pure nitroglycerin does not spontaneously decompose at any ordinary temperature, but, as in the case of guncotton, the presence of free acid combined with heat quickly leads to its decomposition. High temperature alone does not injure thoroughly purified nitroglycerin, and the presence of any acid is determined by shaking a few drops in water and testing the water with *blue* litmus paper. While undergoing decomposition nitroglycerin becomes exceedingly dangerous, the slightest shock causing violent explosion; but unless a very large quantity is involved serious accidents can be prevented by exercising ordinary care. Decomposition of nitroglycerin is detected by the acid reaction on litmus paper and expecially by the explosive becoming *greenish* in appearance. When in this condition nitroglycerin should be very carefully removed and exploded.

Recapitulation.—1. Guncotton is an explosive compound made by immersing pure dry cotton in a mixture of the purest and strongest nitric and sulphuric acids.

2. The best proportions of the acids in the mixture are 1 part of nitric acid to 3 parts of sulphuric acid, while those of the cotton and the mixture are 1 part of the former to 10 parts of the latter.

3. The several steps in the manufacture of guncotton have for their objects:

(1) The thorough drying and cleansing of the materials.
(2) The complete conversion of the cotton into guncotton.
(3) The removal of every trace of free acid from the guncotton.

4. Guncotton is one of the safest explosives known, being absolutely inexplosive when it contains 30 per cent. of water, and is an excellent service explosive.

5. Nitroglycerin is an explosive compound obtained from the action of a mixture of the purest and strongest nitric and sulphuric acids upon pure anhydrous glycerin.

6. The proportions of acids in the mixture are 1 part of nitric acid to 2 parts of sulphuric acid, while those of the glycerin and the mixture are about 1 part of the former to 4 or 5 parts of the latter.

7. Thoroughly purified nitroglycerin is comparatively safe (unless frozen), and not liable to undergo decomposition.

8. When frozen, nitroglycerin becomes dangerously sensitive, and it should be thawed only in the manner prescribed.

9. Both guncotton and nitroglycerin are liable to decompose when they contain free acid and are exposed to high temperatures.

10. When found to be decomposing these explosives should be carefully removed and immediately exploded.

CHAPTER VI

GUNCOTTON POWDERS. DYNAMITE. DETONATORS

Guncotton and nitroglycerin are the most powerful known explosives and, on account of their tremendous explosive force, are unsuitable for many military and industrial purposes. In order to modify and regulate their action they are mixed with other substances, the resulting mixtures being known as *guncotton powders* and *dynamite.*

Dynamite.—At present *dynamite* is a generic term and includes *all explosives made by absorbing liquid nitroglycerin in solid materials which are capable of retaining it.*

The solid material used to absorb nitroglycerin (or the *absorbent*) is technically called the "*dope.*"

The absorbent may be entirely inert and used to convert nitroglycerin from the liquid into the solid form, or, on the other hand, it may itself be an explosive. In the first case the explosive force, bulk for bulk, of the resulting explosive will be diminished, whereas in the second case it will be increased.

Kieselguhr Dynamite or Giant Powder.—This is one of the earliest and best-known forms of dynamite, and consists essentially of a mixture of *kieselguhr*[1] and nitroglycerin, to which is added a very small percentage of sodium (or other alkaline) carbonate to neutralize any traces of free acid that may remain in the nitroglycerin.

[1] Kieselguhr is one of the best-known "dopes," being perfectly inert and possessing very high absorptive power, the best varieties being able to absorb and *retain* 82 per cent. of nitroglycerin. It is largely organic in its composition, containing decomposed shells of myriads of diatoms, which preserve their cellular formation even after calcination.

The kieselguhr is first calcined, pulverized, and thoroughly dried. It is then weighed and put into the mixing troughs.

The nitroglycerin is brought to the mixing house in gutta-percha or lacquered wood-pulp buckets and poured directly upon the absorbent, or it may be brought to the troughs through stout rubber hose.

The proportions vary with the grade of dynamite required.

The mixing is done entirely by hand, the workmen wearing usually india-rubber gloves during the operation. After the nitroglycerin has been entirely absorbed, the dynamite is rubbed through wire sieves so as to distribute the nitroglycerin uniformly throughout the mass.

Properties of Dynamite.—Kieselguhr dynamite is a granular substance, the color of which varies from pearl-gray to reddish-brown; it is of the plastic consistency of moist clay. It should not feel greasy to the touch, nor should there be any trace of free nitroglycerin on the sides of the containing box or cartridge wrapper. Dynamite possesses the physical properties of nitroglycerin and is therefore equally poisonous. Its firing-point is about 356° F., and at this temperature it either burns or explodes; if free from pressure, confinement, jar, or vibration, it burns; otherwise it explodes. High temperatures below its firing-point cause dynamite "to leak," that is, the nitroglycerin exudes from the base (or dope). When this occurs the danger attending liquid nitroglycerin is ever present. Dynamite freezes at about 40° F., and, once frozen, it remains in this condition at temperatures considerably above its freezing-point. Although less sensitive when frozen, the fact that it is still a "high explosive" must always be remembered. When frozen it can be detonated only with difficulty and always with greatly diminished force. It is therefore recommended to thaw frozen dynamite before using it.

All nitroglycerin preparations, when heated gradually up to their exploding points, become dangerously sensitive to the

slightest shock or blow, and, once that point is reached, they no longer ignite but explode violently; and further, on account of the poor conductivity of the material, a very small portion of dynamite in contact with the source of heat may reach this point and cause the explosion of the rest of the mass, which may be considerably below the danger point.

How to Thaw Dynamite When Frozen.—The best way to thaw frozen dynamite is to open the packages carefully and place them in a room where the temperature does not exceed 150° F., and allow the explosive to thaw gradually. A room heated by steam is to be preferred.

If there is not time to follow this method, the best way is to place the cartridges in a water-tight can, and suspend this can in another vessel containing water not hotter than the hand can bear.

Under no circumstances should an attempt be made to thaw any form of dynamite by placing it near a hot fire, nor directly on a hot shovel or plate; nor by leaning it against hot brickwork, steam boilers, or radiators; in short, never attempt to thaw dynamite in any other way than as indicated above.

Explosive Gelatin.—This explosive is made by dissolving the soluble variety of guncotton in nitroglycerin. For military purposes the proportions of the ingredients are about 4 parts of guncotton to 92 parts of nitroglycerin, to which are added 4 parts of *camphor*. The camphor is added to increase the elasticity and solidity of the explosive, while at the same time it reduces its sensitiveness. As might be expected from combining the two strongest known explosives, the resulting compound is the most powerful form of dynamite.

Properties of Explosive Gelatin.—Explosive gelatin has the appearance of a jelly-like paste, which has a honey-yellow color, and a consistency varying from tough leather to ordinary jelly. It does not absorb water, and when placed in it only a very small quantity of nitroglycerin is dissolved

from the surface, which assumes a whitish color, but no further change occurs, no matter how long the explosive remains immersed. Unconfined, it burns, when ignited, with a bright yellow flame and a hissing sound, but does not explode. If, however, it is confined and heated to its ignition point, it explodes violently.

Heated slowly, it explodes at about 399° F.; heated rapidly, it explodes at 464° F. The exact temperature at which explosive gelatin freezes is not definitely known, but it is probably about 40° F. When frozen, it assumes a crystalline structure and a somewhat paler yellow color than when in its normal condition. Unlike the dynamites previously mentioned, *explosive gelatine is much more sensitive to shock when frozen than when in the unfrozen state,* and is readily exploded by the impact of bullets. When unfrozen, it is comparatively insensitive to friction, blows, etc.

On account of its solid form and plastic nature, its great power and comparative safety, explosive gelatin has been regarded as the ideal military explosive.

The original and best grade of explosive gelatin is manufactured by the Nobel Explosive Company of Great Britain. The gelatin manufactured by the Forcite Powder Company in this country is similar in many respects to the Nobel gelatin, but the samples tested seem to have a greater tendency "to leak."

Detonators.—In order to develop the full force of guncotton, nitroglycerin, and explosives derived from them, they should be detonated.

The best-known substance to cause such explosives to detonate is *mercury fulminate.*

Mercury fulminate is itself an explosive, and when dry is very sensitive to all kinds of shocks, and explodes violently when struck, or rubbed or pressed between hard surfaces, or when heated. When moistened so as to contain about 30 per cent. of water it is practically inexplosive. Its most

valuable property for military purposes is that it invariably causes "high explosives"[1] to *detonate* when itself exploded in contact with or very near such substances. When used for this purpose it is mixed with other substances, the usual mixture being 75 parts of mercury fulminate and 25 parts of potassium chlorate, to which is added a little ground glass.

The detonator case is a copper capsule about $1\frac{1}{8}$ inches in length and $\frac{1}{4}$ inch in diameter.

The decomposition is rubbed very fine under water, partially dried and pressed into the capsule, where it dries thoroughly and is covered with a drop of varnish or a thin disk of foil.

According to the amount of fulminate they contain, detonators are graded into *single, double, treble, etc., force caps.* Single force caps contain 3 grains, double 6 grains, etc., up to the strongest or quintuple force cap, which contains 15 grains of fulminate. Detonators are made so as to be fired by means of a "*time fuse*" or by electricity. The ends of detonators to be fired by time fuse are left open to receive the fuse, while electric detonators are closed by means of a plug made of sulphur and ground glass, through which pass two wires. The ends of the wires are connected by a very fine wire (or bridge) around which is wrapped a wisp of dry guncotton. When the electric current passes through the bridge it heats it and the guncotton is ignited and causes the fulminate to detonate.

Recapitulation.—1. On account of their tremendous force, guncotton and nitroglycerin are combined with other substances to modify and regulate their action, the resulting explosives being known as guncotton powders and dynamite.

2. Dynamite is a term which includes all explosives made by absorbing liquid nitroglycerin in a solid material, the absorbent being technically known as the "*dope.*"

[1] This term includes guncotton, nitroglycerin, their derivatives, and practically all explosives capable of detonating.

3. Dynamite is made under various names and in many grades, the strength of any particular grade depending upon the amount of nitroglycerin it contains.

N. B.—For demolitions, submarine mines, and military purposes in general, only the highest grade or strongest dynamite should be used.

4. All guncotton powders and dynamite ("high explosives") should be exploded by means of *detonators*.

5. Detonators (or "blasting caps") may be fired by a "time fuse" or by electricity.

6. The rate of burning of a time fuse should always be determined before it is used.

7. Dynamite should never be used when frozen, and great precaution should be used when it is thawed.

PART III

BALLISTICS

Chapter I. Ballistics.
Chapter II. Interior Ballistics.
Chapter III. Exterior Ballistics.

BALLISTICS

CHAPTER I

BALLISTICS

Gravity.—If a ball be thrown straight upward it will rise with decreasing rapidity to an elevation depending upon the energy with which it is thrown. This energy is the force of propulsion. If there were no such things as gravity and atmospheric resistance the ball would continue to rise indefinitely and would pass on to a point infinitely remote from the earth.

We are all familiar with the action of a magnet upon a nail. The pull of the magnet is called magnetic attraction. Let us suppose that an immense magnet is located at the center of the earth with a power of attraction sufficient to draw objects hurled in the air back to the earth's surface. Such a force would correspond to what is known as gravity.

Gravity then is the force exerted upon any falling mass produced by the earth's attraction, and it is this attraction which gives weight or the quality of heaviness to every tangible object.

The force of gravity is constantly exerted, so that when the ball is hurled upward gravity opposes the force of propulsion until the latter is entirely overcome. When the ball no longer rises and yet has not begun to fall, the two forces are balanced, or an equilibrium has resulted.

Gravity alone, however, has not brought the ball to rest. Another force, known as atmospheric resistance, has assisted the pull of the earth to counteract the force of propulsion.

Atmospheric Resistance.—The atmosphere is the mass of aeriform fluid or air surrounding the earth. It is a tangible substance and, therefore, has a definite weight, being less dense or lighter at higher elevations, than at the earth's surface.

The weight of the atmosphere at sea level is 14.7 pounds per square inch of surface, and the force which the atmosphere exerts in all directions is known as atmospheric pressure. This pressure and the resistance of the atmosphere both resisted the rise of the ball. Without the opposition of gravity and the resistance of the atmosphere the ball would have continued upward indefinitely, for the force of propulsion would never have been overcome, since nothing would have opposed it.

Trajection.—The act of casting a body through the air is called trajection. Hence the course which a body describes in passing through space is called the trajectory.

From the earliest times the method of fighting by hurling objects at an enemy has been employed. This method obviously possesses the merit of enabling one to strike an enemy from a distant and possibly a safe point, provided sufficient skill in trajection is possessed. This necessary element of skill caused the Latins to term the method an art (*ars, artis*), from which they named their mechanical appliances employed therein, *artillaria.* In a general sense the name covered all weapons employed for trajection. Hence it was formerly used for bows and arrows. (I. Sam. xx, 40). From the Latin word came the French *artillerie,* which through modern developments applies only to the various types of cannon.

Artillery, as a name, no longer has a modern application, for, in the strictest sense, the method of trajection now employed is not an art but a science. The word science means knowledge; comprehension or understanding of the truths or facts of any subject. Had the Latins amassed a great

knowledge of trajection by severely testing its possibilities as a method of warfare; had they coördinated and systematized the practice with regard to the laws and forces of nature, they would, no doubt, have derived a name for their machinery from the word *scientia* instead of from the word *ars*.

The foregoing digression has been indulged in with a purpose, for it is all-important for the artillerist to realize at the start that his profession is a science, in the practice of which his natural qualifications may assist, but cannot alone make him proficient, as in the case of an artist.

In our modern field artillery the shell and the shrapnel have been substituted for the arrow and the stone of the ancients; gunpowder has replaced the bow and the sling. But the natural laws of trajection remain the same, for the forces of nature are immutable. The course described by the stone tossed from the primitive catapult is but the trajectory of our steel projectile. In the former case a spring and lever supplied the force of propulsion, in the latter we use gunpowder. And so a rough art has become an intricate and highly developed science.

DEVELOPMENT OF FIELD ARTILLERY

It may be interesting to note here a few facts in connection with the ancient art of trajection, in which the science of ballistics originated. We will begin at a time when the ancient machinery began to be rapidly developed into effective engines of war.

The existing artillery was much improved by Philip and later by the young Alexander, the latter being the Langlois of the ancients. He was the first to give the machines sufficient mobility to make them available in the field. Hitherto they had only been used in sieges, but Alexander placed them on wheels and caused the light artillery to accompany the

foot and mounted troops, thus making of it a third arm of the mobile army. Philip and Alexander also gave to this branch of the service its battery formation. At one time Philip had one hundred and fifty companies on foot and twenty-five reserve batteries in his arsenals.

The catapult was the invention of the Syrians, according to Pliny. It consisted of a huge bow mounted on a platform, the propelling force usually being obtained by a twisted cord or gut applied to the arms of the bow. The bowstring was tightened by a windlass and released by a spring. The catapult shot huge iron-pointed arrows or pikes weighing from ten to three hundred pounds, which had considerable penetrative power. It was capable of carrying nearly one-half mile, and was accurate to five hundred paces.

The ballista was originated by the Phœnicians. It threw stones up to fifty pounds in weight and over, and was the mortar of the ancients. The missile could be cast about half a mile. It consisted of a stout beam or arm of wood one end of which bore a spoon or bowl in which was held the stone, while the other end was secured by a twisted cord or gut mounted in a timber frame. Being brought backward against the twist to a nearly horizontal position by a windlass, and the stone or projectile placed in the spoon or bowl, the arm was suddenly released and flew upward with great power. Its motion was suddenly arrested by an upper transverse beam, or by cords fastened to the framework. The projectile left the spoon at this point and could be directed with considerable accuracy. Red-hot balls and fire-pots were also hurled by the ballista, and sometimes infected corpses were thrown into a besieged city to spread disease.

The Macedonian artillery was extremely effective in the hands of Alexander, who, like Napoleon many centuries later, appreciated the great value of his artillery. In transporting the machines the Macedonians carried only the essential parts, for the heavy timbers could be cut and fitted in any

place where trees were accessible. A horse or a mule could transport the essentials of one ballista or catapult such as they were when perfected by Alexander's engineers.

Cæsar also made constant use of the catapult and the ballista. In his day the larger variety of catapult was capable of projecting heavy beams a horizontal distance of four hundred to eight hundred paces. The small or mobile catapult (*scorpio*) shot heavy lances three to five hundred yards. A burning missile (*falerica*) was also hurled. The big ballista, or siege piece, threw stones four hundred to six hundred paces much in the manner of a mortar, and the *onager* or small ballista was used as a field piece. The smaller types of the *scorpio* and *onager* were designed to be operated by one man.

From the foregoing discussion it is readily seen how the name "Ballistics" has been derived. Now let us see how from the art the science has been evolved.

Following upon the development of the catapult and ballista as machines of war came an artillery in which the power for trajection was supplied by explosives. References to explosive substances like gunpowder, or to burning substances like Greek fire, are to be found in works literally as old as Moses. Among later references, some of the Brahmins of Alexander's time are said by Philostratus to have been able to "overthrow their enemies with tempests and thunderbolts shot from their walls"; Archimedes, at Syracuse, is said by Plutarch to have "cast huge stones from his machines with a great noise"; Caligula is stated by Dion Cassius to have had machines which "imitated thunder and lightning and emitted stones"; and Marcus Graccus in the eighth century gives a recipe of one pound of sulphur, two of willow charcoal and six of saltpeter, for the discharge of what we should call a rocket.

The use of Greek fire was understood as early as the sixth century, but powder was earliest used in China, perhaps a thousand years before Christ, and was introduced to European notice by the Saracens. Neither Schwartz nor Bacon can be

said to be its inventor. Early in the fourteenth century cannon and gunpowder appear to have been known in Florence; in 1338 mention is made of them among the stores in the Tower of London and the arsenal at Rouen; and in 1346 guns—perhaps hand-guns—are said to have been used at Crecy.

It is certain that the Spanish Moors, shortly after 1326, had made the use of gunpowder, fire-arms and cannon well known in western Europe, and by the end of the century they were the common property of all armies. At first the high cost precluded their use except in sieges and the defense of towns; it was much later, at the battle of Rosabeck, in 1382, between the Dutch and French, that field artillery appeared.

At the end of the fourteenth century guns were cast of bronze, copper and iron, and called bombardæ. Some of these were huge specimens, which consumed large charges of powder, and hurled stone balls of from one hundred to one thousand pounds weight. Mortars appeared in Italy about the middle of the fifteenth century (1450).

The French first made use of field artillery, which could be transported in the army trains. That which accompanied Charles VIII to Italy in 1494 was, comparatively speaking, light, rapid of fire and well served. Other nations gradually fell into line, and Gustavus made artillery of really light caliber. So we see that the original impulse to the development of field artillery came from the French just as in the case of the radical changes recently inaugurated by Langlois.

By the middle of the seventeenth century artillery ceased to be merely a guild of cannoneers, as it had long been, and became an inherent part of the army. More intelligence was devoted to, and more money spent on, this arm; it grew in strength and in importance, and was markedly improved. But while artillery service ceased to be a trade, it did not assume the dignity of a recognized special arm except under the great Torstenson, who was to Gustavus what Senarmont and Drouot were to Napoleon over a century and a half later.

Nor was artillery of any great utility in the field until well along in the eighteenth century. Guns, however, in imitation of the Swedes, were lightened, particularly so in France; powder was gradually compounded on better recipes; gunmetal was improved; paper and linen cartridges were introduced; gun carriages were provided with the aiming wedge; and many new styles of guns and mortars and ammunition for them were invented. Science lent its aid to practical men, and not only exhausted chemical ingenuity in preparing powder and metal, but mathematical formulas were made for the artillerymen, and the value of ricochet firing was discovered. Louis XIV founded several artillery schools, and the creation of arsenals was begun. Finally the artillery was organized on a battery and regimental basis, and careful rules were prescribed for the tactics of the guns. These were served by dismounted men and generally hauled by contract horses.

But although sensibly improved during the seventeenth century, the artillery, in addition to being slow of fire, was still unskillfully managed; it stood in small bodies all along the line of battle; and being heavy and hard to move from one position to another, principally because the same guns were used for sieges and for field work, it was far from being, even relatively to the other arms, the weapon which it is to-day.

Mobility as a prime requisite of field artillery received increasing attention from the beginning of the eighteenth century, though the English, including Marlborough, lagged far behind the Continental development. While Frederick the Great did little for his artillery during the early years of his career, he learned by costly experience a lesson from his neglect. The principal defect of his guns was their immobility, in spite of which he was awakened to their value by the service which they rendered him in the battles of Rossbach, Leuthen and Hochkirch. He then set about the improvement of his artillery, increasing the number of field pieces to five for every thousand men of other arms, also creating a horse-artillery

corps of ten light 6-pounders, which was able to accompany his cavalry. In the meantime Austria had brought her field artillery to a higher stage of development than Frederick.

In 1765 Gribeauval, for years called the "father of modern field artillery," undertook the reconstruction of the French system. It was he who separated the artillery into the classes now generally recognized, providing for each a distinct material. By decreasing the length and weight of the pieces, omitting ornamentation and strengthening the carriage, decreasing the windage and the charge, he greatly increased the mobility of the system. Gun mechanism and artillery organization were both highly developed by this distinguished officer, but horse artillery did not make its appearance in the French army until 1791 nor in the English army until 1793.

The improvements which Napoleon made in artillery material were not commensurate with his advance in the organization and tactical employment of field artillery, the principal feature of his development being the formation of divisional and reserve artillery which enabled him to concentrate the fire of separated masses of guns. Hitherto the pieces had been distributed among the battalions in accordance with the system of Gustavus. It is to be noted that both Frederick and Napoleon endeavored to compensate for their losses by increasing the proportion of guns to infantrymen, a fact indicative of the value they attached to their artillery.

In 1803 shrapnel was invented by Major Shrapnel of the British service and Congreve rockets by Sir W. Congreve soon after.[1] The latter were unique reversions to earlier ar-

[1] The derivation of the name of the bayonet is also interesting. It is said to have originated in Bayonne and was first used by General Martinet, the father of rigidity and discipline in drill. The meaning of the term "martinet" is now clear. The great exponent of the bayonet, however, was Suwarrow (Suvaroff, Suvoroff, Suvarov), a Russian field-marshal of Swedish descent born in Finland (1729-1800). His saying to the effect that the bayonet only has sense is well known—a saying which can hardly be accepted as a sound maxim in this day of long-range fire.

tillery weapons, but seem to have been effective. The rocket consisted of a sheet-iron case inclosing the explosive, and was fired from a tube. They were first used at Leipzig (1813) and with great success; also in the Peninsular War, and at Bladensburg against American troops. Improvement in the mobility of the British artillery continued up to the time of the Crimean War. Howitzers were in general use among the European armies.

While there is authority to the effect that rifling and breech-loading had been experimented with as early as 1547 in England, it was not until the Italian War of 1859 that rifled field guns appeared on the battlefield, being one of the many improvements made practical by the French. A breech-loading rifled gun was first used by the British in the China campaign the following year.

By rifling, the effective range of the French piece was increased to about 2,500 yards, the old smooth-bore with an effective range of not over a mile being at a great disadvantage when opposed thereto.

From this time until the Franco-German War (1870) little improvement was made in the efficiency of field guns. During the American Civil War the 12-pounder (smooth-bore) Napoleon gun was extensively used, its effective range being about 1,500 yards. A more accurate and effective gun was the 3-inch rifle of the U. S. Ordnance Department with a range of 2,800 yards. This war did far more for tactics than material. It developed the use of masses of guns to an extent unknown since the days of Napoleon and developed an audacity in the gunner which foreshadowed the Prussian tactics of 1870.

After the Austro-Prussian War of 1866, when it was evident that a conflict with France was at hand, the Prussians made vast strides in the development of their artillery. The guns employed by them in the war of 1870 were steel breech-loading rifles. The French still used a muzzle-loading rifle, though they introduced a machine gun known as the mitrailleuse,

which did not meet the high expectations it at first aroused. The moral effect of this new weapon was very great, however, and in the defense of positions against infantry it was very effective. It was a mistake, of course, to pit them against the German field pieces.

In the contest for military superiority among the great powers of the world, the greatest activity, the heaviest expense, and the largest number of experiments are now in the direction of the development of field artillery. The twenty years succeeding the Franco-German War saw practically no transformations of field-artillery material. At the end of these two decades the usual method of correcting defects by remodeling old types had become impracticable. The years 1890–92 marked the end of the old systems, and the beginning of experiments culminating in a general rearmament, which in 1910 was as shown in the table of field guns included in the introductory part of this book.

The result of this rivalry of nations, then, is the present rapid-fire field gun, a single one of which will deliver more aimed shots in a minute than a whole battery of old guns.

It is not intended to treat of material further, and the foregoing brief outline of its development has been given simply because increased efficiency in material means an advance in the science of ballistics, which subject we are about to investigate.

The subject of ballistics is generally treated under three heads—interior ballistics, exterior ballistics, and ballistics of penetration. The ancients, of course, knew nothing of the first, and little more of the third kind of ballistics, but the general laws of exterior ballistics, which have not been affected by the improved machinery of modern times, were somewhat familiar to them.

CHAPTER II

INTERIOR BALLISTICS

Scope.—Interior ballistics is concerned with the motion of the projectile while in the bore of the gun, and includes a study of the conditions existing in the bore from the moment of ignition of the powder charge to the moment that the projectile leaves the muzzle.

Practical Results.—The circumstances attending the combustion of the powder, the pressures exerted by the gases at different points of the bore, and the velocities impressed upon the projectile, all of which may be demonstrated mathematically, are subjects belonging to the study of Interior Ballistics.

The practical results of the study lie in the application of the deduced formulæ which connect the flight and the course of the projectile with the velocities and pressures. By means of the formulæ we may determine the stresses to which a gun is subjected by the pressure of the powder gases, and the dimensions of the chamber and bore, and the weight of the powder necessary to produce in a projectile a desired velocity. The action of different powders may be compared and the most suitable powder selected for a particular gun. The interior pressures at all points along the bore being made known, the thickness required in the walls of the gun to safely withstand these pressures is determined from the principles of the gun construction. And so we see that the amount of powder employed, the velocity of a projectile, the shape and dimensions of a gun are not merely accidental, but are based upon a series of exact investigations, all of which are within the scope of Interior Ballistics.

Action of Powder in the Gun.—Explosives, as we have seen, are substances which, under the influence of some disturbing agency, enter into a chemical reaction accompanied by the production of gases and the evolution of much heat. The powder used as a charge for the gun possesses a certain potential force or latent power. Upon combustion the potential force of the explosive becomes a kinetic or moving force, which is made use of for the purpose of projecting the missile through the air.

The effects of the explosion of the powder upon the projectile and the gun are dependent on the quantity of gas evolved, on the accompanying heat, and on the rapidity of the reaction. It is readily understood that the greater the volume of gas evolved at the temperature of explosion, the greater the pressure exerted on the bore of the gun. The rate of evolution of the gas of gunpowder is known as the velocity of emission.

The pressure per unit of surface exerted by the gases from unit weight of the explosive, the gases occupying unit volume at the temperature of explosion, is called the force of the explosive. The progressive emission of gas from gunpowder produces a propelling effect by causing a gradual increase of pressure on the base of the projectile, which is made use of instead of the shock resulting from a more sudden conversion or detonation.

Heat and Work.—The quantity of heat determines the quantity of work that may be effected by the explosion. The projection of the missile from the gun is the effect produced by the conversion of the heat of the explosion into work. The total work that can be performed by the gas from unit weight of the explosive under indefinite adiabatic expansion measures the potential of the explosive.

Adiabatic Expansion.—By adiabatic expansion is meant an expansion of the gas in such a manner that it performs work without giving heat or receiving it. In this case, the

heat in the gas is converted into work, the temperature of the gas diminishing.

In order to understand the great propelling power of an explosive, due to the expansion of the gas, some idea of the working power of heat, which is the cause of the expansion of the gas, must be had.

The working power of heat or its mechanical value is measured in thermal units. A thermal unit is the heat required to raise a pound of water at the freezing-point one degree in temperature. The mechanical equivalent of heat is the work equivalent of a thermal unit; that is, it is the work that can be performed by the amount of heat required to raise a pound of water at the freezing-point one degree. For the Fahrenheit scale the M. E. is 778 foot-pounds; and for the Centigrade scale 1,400.4 foot-pounds. In other words, the heat which will raise the temperature of one pound of water one degree Fahrenheit will move one pound 778 feet or 778 pounds one foot; and the heat which will raise the temperature of one pound of water one degrée Centigrade will move one pound 1,400.4 feet or 1,400.4 pounds one foot. This gives us some idea then of the value of gunpowder as the means of producing heat.

That which actually occurs when powder is ignited is as follows: In the first place, the powder is converted into a volume of gas greater than that of the powder; in the second place, the heat generated by the explosion expands the volume of this gas, and increases its pressure. The pressure of the gas is equal in all directions. Unless the gun breaks, the expansion will naturally follow the line of least resistance, which is along the bore. The pressure due to the expansion in this direction expels the projectile.

Density of powder is the ratio of the weight of a given volume of powder to the weight of an equal volume of water. In determining density the volume considered is the volume actually occupied by solid powder.

Gravimetric density of powder is the mean density of the contents of the volume that is exactly filled by the powder charge. The air spaces between the grains are considered as well as the solid powder in the charge. The gravimetric density is obtained by dividing the weight of the charge by the weight of water that will fill the volume occupied by the charge. It is evident that, if a solid block of powder of a given density be broken up into grains, the volume occupied by the powder will increase and will be dependent on the form and size of the grains. While the actual density of the solid powder does not change, the gravimetric density will depend upon the granulation.

The Gun.—The gun serves two purposes; first, as the containing vessel for the explosive, and a means of confining the gases in such a way that the pressure of expansion will be exerted upon the base of the projectile; and, second, to give the projectile the proper direction.

So long as the gas continues to exert a forward pressure upon the base of the projectile, it continues to accelerate the motion of the projectile, the velocity of which increases until it passes out of the muzzle, and the pressure on its base ceases.

Capacity of Gun.—The powder for a gun of any caliber and length has the greatest efficiency when in grains of such shape and dimensions that the charge of least weight produces the desired muzzle velocity within the allowed maximum pressure. The powder that produces these effects may be considered the standard powder for the gun.

The maximum pressure is dependent on the initial surface of the powder charge. A powder with greater initial surface than the standard powder, that is, a powder of smaller granulation, will produce a greater maximum pressure and therefore will be a quick powder for the gun, and a powder of larger granulation will be a slow powder.

We would get the greatest possible effect out of a charge

of powder if the gun were made long enough to contain the whole of the powder gases, so that the forward pressure on the base of the projectile would cease just as the shell reached the muzzle. Such a gun would, however, be unwieldy, and in practice we cut the gun short and allow a good deal of the gas pressure to go to waste out of the muzzle. It is readily seen with how much greater force the missile would be thrown if the waste pressure could be brought to bear upon it in addition to that which is actually employed.

Length of Gun.—The length of a gun is expressed by the number of calibers in its total length. Modern rapid-fire field guns are from 27 to 35 calibers long. A caliber is the diameter of the bore measured between opposite ribs of the rifling. Generally speaking, the bore is measured from the face of the breech-block to the muzzle.

Chamber of Gun.—The bore of a gun is divided, for the purpose of internal ballistics only, into two parts, the chamber and the bore proper. The powder does not completely fill the chamber, nor is it a solid mass, but it is in granulated form. If the powder charge in a 3-inch shell were compressed into a solid block, it would be found to fill a small portion of the chamber, possibly a third. On ignition the powder gases first fill the chamber. The higher the velocity of ignition, that is, the more rapidly the gas is evolved from the powder, the sooner will the pressure of the chamber overcome the resistance of the projectile, causing it to move up the bore. This, in a field gun, occurs when the pressure rises to about 1½ tons to the square inch. Henceforward the pressure of the gas acts as an accelerating force upon the projectile until the latter leaves the muzzle.

Effects of Powder on Design of Gun.—In the design of a gun, the caliber, weight of projectile, and muzzle velocity being fixed, consideration must be given to the powder in order that the size of chamber, length of gun, and thickness of walls throughout the length may be determined. To

produce a given velocity in a gun a larger charge of powder that is slow for the gun is required than is of a powder that is quicker. The larger charge requires a larger chamber space, and thus increases the diameter of the gun over the chamber. The maximum pressure being less than with the quicker powder, the walls of the chamber may contain less metal. The slow powder will give higher pressure along the chase, therefore the walls of the gun must here be thicker, the weight of the gun being increased throughout its length.

If we do not wish to increase the diameter of the chamber we must, for slow powder, lengthen the gun in order to get the desired velocity. On the other hand, with a powder that is too quick for the gun very high and dangerous pressures are encountered, requiring excessive thickness of the walls over the powder chamber. The gun in this case may be thinner walled along the chase.

It is evident from the foregoing considerations that each gun must be designed with a particular powder in view, and that a gun so designed and constructed will not be as efficient with any other powder.

Now let us follow the evolution of gunpowder and the consequent changes in the design of the guns.

Forty years ago the only explosive used in guns was coarse black powder. The whole of the charge was converted into gas almost immediately upon ignition, thus developing a very high pressure in the powder-chamber upon ignition, which rapidly fell as the shell moved up the bore. Guns of this period were, therefore, made of a very pronounced bottle shape, enormously thick at the breech. The old-time field-piece was, of course, lighter in metal, because the powder charge, and therefore the pressure, was comparatively small; but the general shape was much the same as that of the guns used in permanent works and water-batteries. As an improvement on the old form of black powder, pebble powder, in the form of cubical grains of from one-half inch to one and one-

half inches, was introduced. It was found that the cubes burned more slowly than the grains, and, since the gas was evolved more slowly, a smaller initial pressure resulted, and a better maintained pressure as the projectile moved up the bore. Guns were then made thinner at the breech and thicker at the muzzle.

Prismatic powder, pressed into large six-sided prisms, was the next step; this was followed by slow-burning brown powder, known as cocoa powder. Now we have smokeless powder, in thick cords, tubes or tapes, for long guns, and

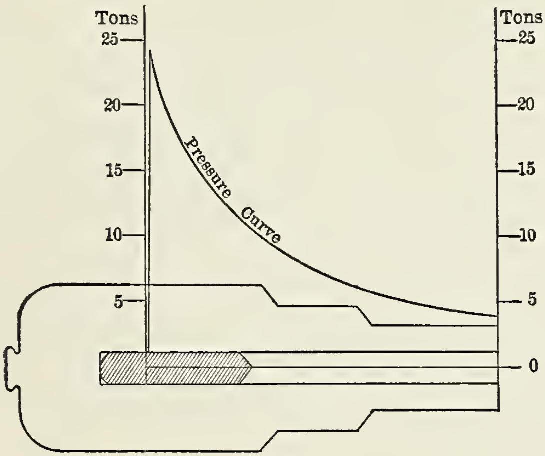


Fig. 1.

fine strings for short ones. This has enabled us to adjust the pressures in the bore so as to get the maximum of work out of the gun with the minimum of metal. It is to be observed that to-day there is slight difference in the metal at the breech and at the muzzle.

A simple and convenient means of showing graphically the pressure in any gun is by the use of pressure curves.

Figure 1 gives the curve for a certain 12-inch gun of old type when black powder was used.

Here the height of the curve represents the pressure in tons at that particular point in the bore. We note how the pressure rises from zero to 24 tons per square inch before the shell begins to move, and runs up to 25 tons before the shell has traveled half of its length. The pressure then rapidly falls, as the stopper, so to speak, is drawn out, till at the muzzle it is only 3 tons per square inch.

As a contrast to that of the old 12-inch gun, the curve

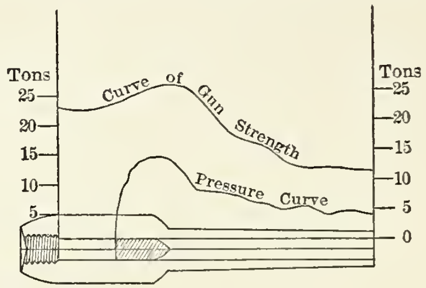


FIG. 2.

for a modern 6-inch gun is shown. The pressure nowhere exceeds 15 tons per square inch and diminishes gradually toward the muzzle. We may also note how in both cases the pressure curve corresponds in a general way to the profile of the guns. This is, as has been shown, because the gun was cast or constructed to withstand the pressure to which it would be subjected, its shape not being merely accidental.

CHAPTER III

EXTERIOR BALLISTICS

Exterior ballistics treats of the motion of a projectile after it has left the piece.

We have already seen that the trajectory is the course of the projectile during its flight. To be mathematically exact, it is the curve GMT, described by the center of gravity of the projectile during its passage through the air.

Every trajectory is theoretically an analytical curve. That is, it is such a curve that it may be analyzed with respect to its ordinates. In other words, the horizontal distance of any point on the curve bears a definite and fixed relation to the vertical distance of that point, from another given point.

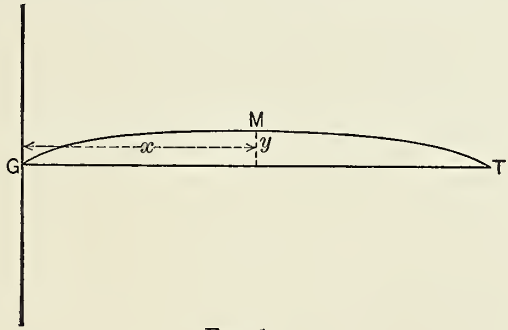


FIG. 1.

Thus in Figure 1, the horizontal ordinate x, of the point M, bears a definite relation to the vertical ordinate y, and given certain other factors, such as the resistance of the air, the velocity of the projectile, etc., etc., knowing the value of either ordinate, the other may be determined.

While a certain motion of the projectile to be hereinafter considered effects the trajectory, the curve ordinarily considered is the projection of the actual curve upon the vertical plane of fire. This projection so nearly agrees with the actual trajectory that the results obtained are practically correct.

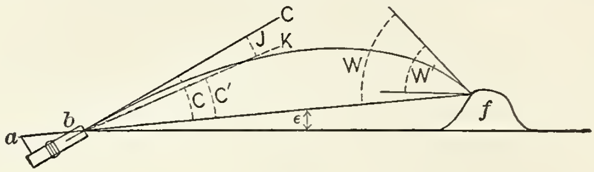


FIG. 2.

The Range, bf, (Figure 2) is the distance from the muzzle of the gun to the target.

The Line of Sight, abf, is the straight line passing through the sights and the point aimed at.

*The Line of Departure, b*C, is the prolongation of the axis of the bore at the instant the projectile leaves the gun.

*The Line of Fire, b*K, is the prolongation of the axis of the bore before the projectile leaves the piece.

Jump.—When the piece is discharged the muzzle of the piece jumps upward, while the projectile is moving through the bore. The movement of the axis is due to the elasticity of the parts of the carriage, to the play in the trunnion beds and between the parts of the carriage, and in some cases to the action of the elevating device as the gun recoils. The jump must be determined by experiment for the individual piece in its particular mounting, and for the projectile and the powder charge used. Jump increases the angle of elevation, so that the angle of departure is greater than the former. It is measured, therefore, by the angle J, or the angle between the line of fire and the line of departure.

The Plane of Fire or *Plane of Departure* is the vertical plane through the line of fire or through the line of departure.

The Angle of Position or Angle of Sight, ε, is the angle made by the line of sight with the horizontal. This angle is referred to as the Angle of Site in Practical Gunnery.

The Angle of Departure, C, is the angle made by the line of departure with the line of sight.

The Quadrant Angle of Departure, $C + \varepsilon$, is the angle made by the line of departure with the horizontal.

The Angle of Elevation, C', is the angle between the line of sight and the line of fire, or with the axis of the piece when the gun is aimed.

The Point of Fall, or Point of Impact, f, is the point at which the projectile strikes.

The Angle of Fall, W, is the angle made by the tangent to the trajectory with the line of sight at the point of fall.

The Striking Angle, W', is the angle made by the tangent to the trajectory with the horizontal at the point of fall.

Velocity is the rate of motion or the rate at which a body changes its position in space. It is measured in feet per second.

Initial Velocity is the velocity of the projectile at the muzzle. It is sometimes spoken of as muzzle velocity.

Remaining Velocity is the velocity at any point of the trajectory intermediate between the muzzle and the point of impact.

Final Velocity is the velocity at the end of the range.

Fire Classified as to Angle of Elevation.—*Direct Fire* is from guns with service charges at all angles of elevation not exceeding 15°.

Indirect or Curved Fire is from guns with less than service charges, and from howitzers and mortars, at all angles not exceeding 15°.

High-Angle Fire is from guns, howitzers, and mortars, at any angle exceeding 15°.

Fire Classified as to Direction.—*Front or Frontal Fire* is that which is directed perpendicularly, or nearly so, to the front of the target.

Oblique Fire is that which is directed obliquely to the front of the target. Frontal fire penetrates the target at one point.

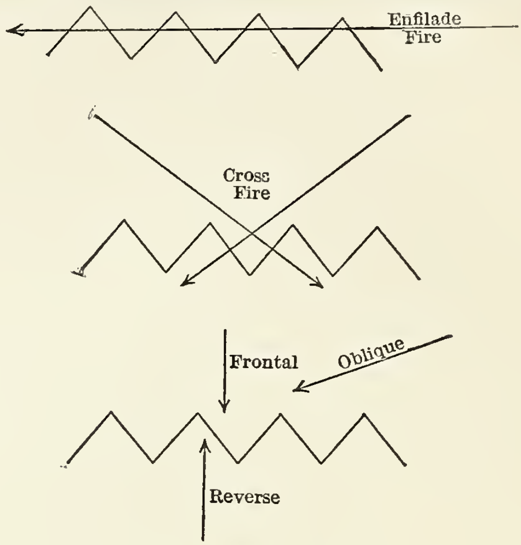


Fig. 3.

Oblique fire not only penetrates the target, but renders a greater space in advance thereof untenable.

Enfilade or Raking Fire is that which rakes a target, the gun from which it is delivered being on a flank of the target. It is naturally the most destructive and demoralizing form of fire.

Flanking Fire is one directed along the front of, or nearly parallel to, the line to be flanked or defended. The term has respect to the position of the troops to which the gun belongs.

Reverse Fire is fire delivered upon the target by a gun in rear thereof.

Cross-Fire is where projectiles from guns in different positions cross one another at a particular point of ground.

The Unimpeded Motion of a Projectile.—Suppose a shell be fired in vacuo in a horizontal direction with a velocity of 1,000 feet per second. Then its path will be determined

by the two forces acting on it, namely, the impetus of the shell, which tends to carry it forward in the direction in which it started; and the force of gravity, which tends to pull it down to the earth.

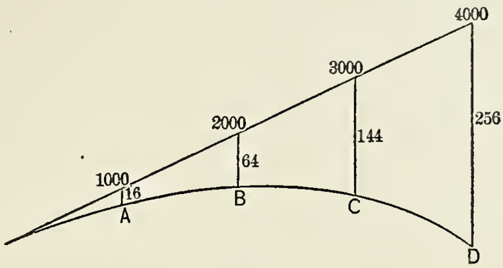


Fig. 4.

We know that a falling body drops (neglecting decimals), $\frac{1}{2}gt^2$, or

$16 \times 1^2 =$	16	feet by the end of the	first	second
$16 \times 2^2 =$	64	" " " " " "	second	"
$16 \times 3^2 =$	144	" " " " " "	third	"
$16 \times 4^2 =$	256	" " " " " "	fourth	"
$16 \times 5^2 =$	400	" " " " " "	fifth	"

and so on.

Then by the end of the first second the shell will have traveled 1,000 feet forward and have dropped 16 feet downward, so that its position will be at A.

At the end of the next second it will have traveled another 1,000 feet forward, and will have dropped altogether 64 feet, and its position will be at B; and so on.

If the shell be fired in a vacuum, as is imagined in the preceding paragraphs, the curve of the trajectory would be a parabola. But in practice, as will be explained hereafter, the shape of the trajectory is considerably modified by the resistance of the air.

Shell Fired Vertically.—If a shell be fired straight up into the air, at a velocity of 1,000 feet per second, it will

continue to fly upward until the ever-increasing downward velocity, due to gravity, exceeds 1,000 feet per second, when it will begin to fall.

To work this out practically we must use the formula:

$$V = gt.$$

Here V is the velocity, g the acceleration due to gravity, and t the time in seconds. Now g is always the same, since the force of gravity does not vary, and is equal to 32 feet (strictly 32.2 feet) per second.

Some confusion may arise in the student's mind between the 32 feet of acceleration due to gravity, and the 16 feet through which the body drops in the first second.

Now if a body falls from rest, it falls faster and faster, until at the end of the first second it is traveling at the rate of 32 feet per second. This acceleration of velocity from 0 to 32 feet per second is "g," and every unsupported body gets an extra velocity of 32 feet imparted to it by gravity every second. If the body be supported, then the effect of gravity is to cause a continuous stress on the support.

It will be apparent on consideration that the distance through which a body falls in the first second is not 32 feet, since the body only attains that velocity at the end of the second. The distance corresponds to the mean velocity of the body during that second, which is half-way between 0 and 32, or 16 feet

To return to the question of the shell fired vertically upward. As we have stated, $V = gt$, that is, for every second that the shell is in the air it acquires an increasing downward velocity of 32 feet. At the end of 10 seconds it will have acquired 320 feet per second downward velocity; but since its impetus continues to drive it upward at 1,000 feet per second, its actual remaining upward velocity will be 680 feet per second.

At the end of 30 seconds its downward velocity will be

960 feet, and at the end of 32 seconds 1,024 feet; so that at some time in the 32d second (actually at 31¼ seconds) the upward velocity will balance the downward velocity, and the shell will begin to fall again. Thenceforward, the velocity will increase at the rate of 32 feet per second until the shell reaches the earth again.

Its velocity on reaching the earth will be 31¼ multiplied by 32, or 1,000 feet per second, which we see is equal to that with which it started.

Elevation.—Since the shell is falling during the whole time of flight, then in order to reach the target it must be directed at a point above the target. The height of this point must be equal to the distance through which the shell falls during the time of flight. (See Figure 5.)

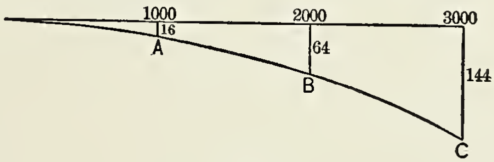


FIG. 5.

Thus if the shell be fired at an object 3,000 feet distant with a velocity of 1,000 feet per second, it will take 3 seconds to reach the target. And since in 3 seconds the shell will fall $16 \times 3^2 = 144$ feet, therefore it must be directed at a point 144 feet above the target.

Since the parabola which a shell describes in vacuo is a regular curve, with its ascending and descending branches alike, the greatest height attained by the shell will be at a point half-way between the range.

For simplicity, we will take the case of a shell with a M. V. of 1,000 feet and a time of flight of 4 seconds. The point at which the shell is aimed will be $16 \times 4^2 = 256$ feet above the target, and point C in the center of the range will be 128 feet high. Half-way down the range the shell will have been

falling two seconds, and will be 64 feet below C, or 128 − 64 = 64. This is one-quarter of the height of A, and this proposition holds good for any shell describing a parabola.

Since the height of A in feet is sixteen times the square

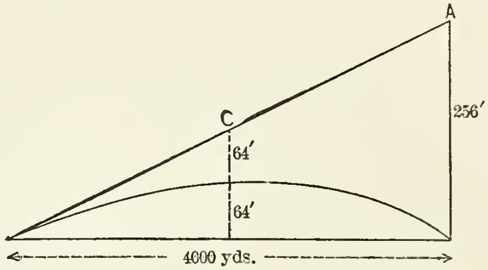


FIG. 6.

of the time of flight, therefore the greatest height attained by the shell is four times the square of the time of flight, or

$$H = 4T^2.$$

This formula is given here because it is practically useful. At medium ranges the first half of the trajectory of a field gun fired under ordinary conditions is not very different from a parabola, and the formula is sufficiently near the truth for practical purposes. The time of flight is always known either from the range table or the fuse scale, and this gives us a ready means of determining the height of the trajectory.

The Rigidity of the Trajectory.—According to the principle of the rigidity of the trajectory, which may be mathematically demonstrated, the relations existing between the curve and the chord representing the range are practically the same for direct fire, whether the chord be horizontal or at an angle to the horizontal. In other words, the curve is practically the same whether the target be on the same level with the piece, or above or below it.

Thus, if the ranges GT and GT′ (Figure 7) are equal, the curve GOT bears the same relation to its chord, GT,

that the curve GO′T′ bears to its chord GT′, and the maximum ordinates at O′ and O are equal.

The Motion of a Projectile in Air.—A projectile traveling through the air experiences a certain resistance, which shortens the distance of its flight and alters the shape of the trajectory.

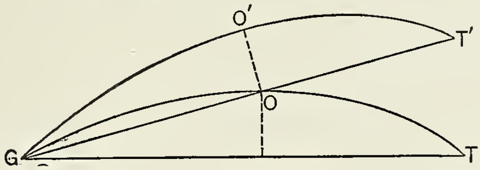


FIG. 7.

This resistance is greater at high than at low velocities, but the rate of increase does not follow any simple rule.

Up to about 800 feet per second it increases as the square of the velocity; that is, a shell traveling at 300 feet per second experiences 9 times as much resistance as one traveling at 100 feet per second. Above 800 fs. the resistance increases in a higher ratio. For velocities between 1,000 and 2,500 feet per second the resistance may be said to increase roughly as the cube of the velocity.

It will be readily understood that the resistance is in direct proportion to the surface offered to the air, that is to the cross section of the projectile. This is apparent, since two projectiles side by side, each one square inch in cross section, will experience twice as much resistance as one such projectile.

Shape of Head.—The resistance is affected in a marked degree by the shape of the head of the shell. It is found that in a shell of the usual form the shape of the shoulders is more important than that of the actual point. It is suggested as an explanation of this that as the air streams outward from the point to pass over the shoulders of the shell it leaves a partial vacuum in front of the point, while the

main air-pressure comes near the shoulders. But when a shell with an ogive of 5 or 6 calibers radius is used, the shape of the point becomes important, as determining the stream lines, or direction of the currents of air which flow over the shoulders of the shell.

Smoothness.—It is also found that a modern smooth steel shell with driving-band meets with less resistance than the old cast-iron studded shell.

Steadiness.—If a shell wobbles and travels shoulder first, its cross-section is naturally larger, and the resistance it meets with greater, than if it traveled point first. Modern shell are steadier in flight than those formerly used.

Taper-Base Shell.—The ideal shape of a shell intended to travel through the air with the minimum of resistance is that of a Whitehead torpedo, with a long tapering "tail." Theoretically, the shape of the base is more important than that of the head—just as, in ship designing, a fine run is found even more conducive to speed than a sharp entrance. The flat sawed-off bottom of the service shell is objectionable, for several reasons. It forms a partial vacuum behind it, causing an unbalanced air-pressure on the head of the shell, and the air rushing into this vacuum forms eddies which tend to unsteady the shell. It would therefore appear desirable to introduce a more scientific form of projectile. This idea was carried out successfully in the original Whitworth solid shot, which was the first accurate artillery projectile ever invented. But modern experiments have given less favorable results. The Zalinski torpedo shell, fired from an air-gun, had a habit of pitching in unexpected places. And at a trial carried out in Switzerland in 1903 it was found that although the taper-base shell ranged further than the ordinary pattern, they were decidedly inaccurate in flight. It would, however, be a mistake to condemn a theoretically sound design on the strength of a single experimental series. The failure of the Swiss experiments only showed that *some-*

thing was wrong—probably the twist of the rifling was unsuited to these particular shell. It is to be hoped, therefore, that, in spite of the obvious manufacturing difficulties, modern science may evolve a better shape than that of the cylindro-ogival shell which forms our present equipment.

Density of Air.—When the barometer is high the air is compressed and is denser than when it is low; on the other hand, when the thermometer is high the air expands and is less dense than when the temperature is low. Since the resistance to a projectile is greater when the air is denser, the pressure and temperature must be taken into account in all accurate work, such as practice for range and accuracy.

Temperature.—Besides the effect of the temperature on the density of the air, it has another and practically much more important action, namely, its effect upon the powder. All modern smokeless powders are comparatively sensitive to changes in temperature, and a rise in the thermometer usually means an increase of muzzle velocity. The amount of such increase varies for each particular size and sample of powder, and cannot well be tabulated.

Flatness of Trajectory and Dangerous Space.—A trajectory may be flat, that is approaching a straight line, or eccentric, that is very curved.

The perpendicular let fall from the highest point of the curve to the line of sight is the maximum ordinate of the trajectory.

We have seen that the curve of the trajectory in vacuo would be a parabola. The maximum ordinate in such a case would be at the middle of the range, since the curve is regular. In air, however, the angle of fall is always greater than the angle of departure, and hence the highest point of a trajectory is nearer the point of fall than the piece. As the range increases, then the maximum ordinate creeps toward the target. O_1 is at the middle of range G_1T_1, but O_2 is nearer T_2 than G_1 by the distance CO_2.

A shell which travels high above the earth to reach the target is clearly ineffective against an enemy standing anywhere except at the exact point where the shell pitches. On the other hand, a shell which flies along comparatively close to the ground will strike a six-foot man standing anywhere between the

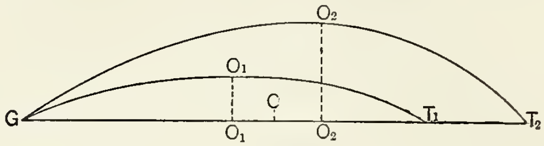


Fig. 8.

place where the shell pitches and the point where the trajectory comes within six feet of the ground. This space over which an enemy is liable to be struck by a projectile fired at a given point is called the dangerous zone, and it is the object of the gun-designer to make this dangerous zone as deep as possible; not so much on account of the shell as on account of the shrapnel bullets which issue from it. This is secured by flatness of trajectory—that is, by projecting the shell so that the height above the earth which it reaches is as small as possible.

The dangerous space for any object may be readily determined. Suppose an object is 6 feet high. When the projectile leaves the piece it ascends and then descends. If we determine the distance from the piece at which the height of the trajectory is 6 feet, it is evident that for every point beyond this distance, in the descending branch of the trajectory, the height will be less than 6 feet, and the object will be struck. The dangerous space, then, is the difference between the whole range and the distance to the point at which the trajectory is 6 feet high.

It is also evident that in general there will be two points of the trajectory whose heights are the same—one point in the ascending, and one in the descending branch. The latter only is considered.

It is evident that very flat trajectories possess certain advantages, for if the maximum ordinate is less than the height of animate objects they will be struck at any point of the range. The total range is then dangerous space and when such is the case it is called the maximum continuous dangerous space, or the danger range.

An error in estimating range is also of less importance with such a trajectory, since if the projectile reach the point where the target is actually situated it will be struck even though it be not where the projectile would have fallen.

It will now be more readily understood why long ranges, where trajectories are high and have large angles of fall, are less effective than short ranges, where the dangerous space is greater due to the flatness of the trajectories and the consequent smallness of the angles of fall. The accuracy of fire may be as great in one case as in the other. At long ranges, however, a very limited space is subjected to the fire—that is the point at which the projectile actually falls; whereas at short ranges a considerable space in front of the target is swept while the projectile is traversing the dangerous space.

The advantage of short ranges with respect to dangerous

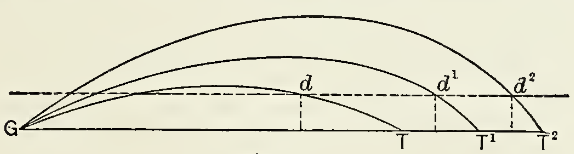


FIG. 9.

space, and therefore the effectiveness of the fire, is illustrated in the foregoing figure in which the horizontal dotted line is at the height of a man's head from the ground. As the angle of fall increases the danger zone diminishes.

The danger zone, dT, of the range GT is seen to be much deeper toward G than is d^1T^1, and d^2T^2.

High Velocity.—Now we have seen that it is necessary

to project a shell to a certain height in order to reach a target in a given number of seconds. And no human power can alter the height through which a shell falls in a given time. To obtain a flat trajectory, therefore, all that we can do is to reduce the time of flight as much as possible.

If the velocity of a shell is 3,000 feet per second, it would reach a target 3,000 yards distant in one second, and the greatest height, $4T^2$, would be 4 feet. If the velocity were 1,500 fs. the time of flight would be 2 seconds, and the greatest height 16 feet, giving a dangerous zone of about 200 yards in front of the target. Thus, we see that to procure a flat trajectory and deep dangerous zone we must have a high velocity, enabling us to use a small angle of elevation.

Angle of Descent.—Flatness of trajectory is estimated in practice by the smallness of the angle of descent. The field gunner's object is to burst his shrapnel so that the bullets do not pitch straight forward into the ground, but sweep along it, so as to produce good effect in spite of inevitable errors of range. For this he requires a small angle of descent, which is only possible with a high muzzle velocity.

Greatest Possible Range.—The greatest possible range in vacuo is obtained when the angle of elevation is 45 degrees. When fired in air the angle giving the greatest range is not materially different, being between 40 and 43 degrees Little is gained by increasing the angle of elevation beyond 35 degrees.

Rifling.—Rifling is a means of imparting rotation to the shell. In all modern guns this is effected by cutting helical grooves down the bore, leaving raised ribs called "lands" between them. A band of soft copper is secured round the shell near the base. On discharge the shell with its copper driving-band is projected up the bore; the ribs cut into the soft copper and force the shell to follow their helical course and to rotate. This rotation continues, somewhat diminished by the friction of the air, to the end of the shell's flight.

The only method of rifling now in use is the polygroove

system (so called from the large number of small grooves) and the copper driving band.

Object of Rifling.—Any rapidly rotating body tends to preserve the direction of its axis of rotation—that is, to keep in the same direction in which it pointed when first made to rotate. A familiar instance of this is the spinning top.

Not only does a spinning body tend to preserve the direction of its axis of rotation when left alone, but it actively resists any attempt to change that direction.

Thus, if we attempt to upset a spinning top by striking it with a ruler, we shall find some difficulty in doing so. Instead of overturning, the top will fly off sideways, still keeping vertical.

This property of rotating bodies is turned to account to make the shell travel point first during its flight. But for the spin given to the shell it would soon turn over and fly sideways when its direction would become erratic and its range would be much reduced.

The object of rifling may, then, be said to be to enable a gun to fire an elongated projectile with accuracy.

Advantages of Elongated Projectiles.—Since a shell three calibers long has a cross-section only one-third of that of a spherical shell of the same weight, it can be fired from a much smaller and lighter gun. And since it only opposes to the air a resistance one-third of that of the spherical shell, it ranges much further. And moreover since in penetrating an obstacle it makes a hole only one-third the size of that made by a spherical shell, it will penetrate more readily.

These advantages may be said to be due to rifling, which renders it possible to use the elongated shell.

Twist of Rifling.—A spinning top is acted on by its weight, which constantly tends to make it fall flat, and its energy of rotation, which keeps it vertical. When, owing to the friction of the peg of the top, the energy of rotation is sufficiently diminished, the top overbalances.

Now, with a shell, the force tending to overturn it is the pressure due to the resistance of the air, and that tending to keep it straight is the rotation due to the rifling. The former tends to constantly diminish as the shell expends its velocity in overcoming the resistance of the air; but the spin is affected only by the surface-friction between the shell and the air, and reduces it to a less extent. For flat trajectories, it follows, then, that if we give the shell enough spin to keep it straight at starting, this will suffice to keep it point foremost to the end of its flight.

Minimum Twist.—The longer the shell in proportion to its diameter the greater the amount of spin required. It will be afterwards seen that it is desirable not to allow an undue amount, as this increases the lateral curvature of the path of the shell.

Uniform and Increasing Twist.—It will be readily understood that if a heavy shell has a high velocity of rotation suddenly forced upon it, this must cause a severe strain both on the shell and on the gun. To avoid this, the grooves of the rifling are made to run at first straight down the gun, gradually increasing in inclination or "pitch" till the full velocity of rotation is attained. This is known as an "increasing twist," in contradistinction to the older "uniform twist," in which the pitch of the rifling was the same all down the bore.

The increasing twist, however, has the advantage of causing greater friction in the bore and consequent loss of velocity. For the indents made by the lands in the driving-band have to be forcibly displaced as the shell travels down the bore and the inclination of the lands alter.

Position of the Driving-Band.—At first sight it would seem desirable to put the driving-band as near the center of gravity of the shell as possible, but in practice this is not the case. The walls are too thin at the center of the shell to carry the driving-band. Moreover, the body of the shell

can never be a close fit in the bore, and after the driving-band had emerged from the muzzle it would be followed by some 6 inches of ill-fitting body, with the powder-gases escaping past one side of it, which would unsteady the shell. Accordingly the driving-band is always set as far back as possible, leaving only sufficient metal behind it to afford a grip for the cartridge case.

Forward Steadying Band.—The unsteadiness or oscillation of the shell in the bore, due to its imperfect fit, is a serious cause of inaccurate shooting. Attempts have been made to overcome this by fitting a forward band in addition to the driving-band. It is said that the new Austrian field shell has a steadying band of this nature. The subject is beset with difficulties. If an increasing twist is used, the forward band must on no account take the rifling. If the forward band is to be a good fit in the bore, then the bands must be eased at the breech in order to enable the shell to be rammed home. The walls have to be thickened at the shoulder to take the band. In spite of these difficulties, it would seem worth while to try the steadying band in field guns with uniform twist of rifling, in order to obtain increasing accuracy for fire at shielded guns.

Drift.—The tendency of a projectile fired from a gun rifled with a right-hand twist is to drift or whirl out of the plane of fire to the right. This divergence increases rapidly with the range—about as the square thereof. The rough correction of deflection for drift is set forth in paragraph 327 Drill Regulations at 3 mils up to 3,500 yards and 5 mils for longer ranges.

The subject of drift is a very difficult and complicated one and we understand few of the laws governing this motion.

Although the effect of the resistance of the air tends to keep the shell pointing in the direction of its motion, yet the spin of the shell constantly resists this tendency, and tries to keep the shell parallel to its original direction. The

result is a compromise, and the shell travels with its nose cocked in the air, well above the line of the trajectory.

Now if we remember that the shell, viewed from behind, is spinning in the direction of the hands of a clock, then it will be evident that its friction against the air resistance, which takes it below the center, must tend to make the shell gradually deviate to the right. And since the spin of the shell diminishes more slowly than the forward velocity, therefore the path of the shell curves more and more to the right.

Thus if we suppose that the spin of the shell carries it ten feet to the right every second, then in the first second the shell will travel say 1,500 feet forward and 10 feet sideways, and will have acquired a side velocity, at right angles to the line of fire, of 20 feet per second. During the next second this side velocity will increase to 40 feet per second, during the next to 60 feet, and so on; while all the time the forward velocity will be decreasing. It is quite conceivable that if the range were long enough and the twist sharp enough the shell would end by drifting almost square across the line of fire.

A good instance of drift is the behavior of a sliced golf ball. Here we have a projectile roughened so that the effect of the twist makes itself fully felt, a comparatively low velocity, and a sharp spin; and the result is often that the ball pitches nearly as far off the course as it carries from the tee.

It must not be supposed that the above is either a full account or a mathematically correct statement of the behavior of a rifled projectile. It merely furnishes a working hypothesis sufficiently near the truth for the purposes of the practical gunner.

Persistence of Spin.—It was formerly supposed that the spin of the shell was but little affected by the air-resistance, and that, for flat trajectories, the spin continued almost undiminished to the end of the shell's flight. Recent experiments with mechanical fuses depending for their action on

the spin of the shell have caused this view to be modified. It is found that a R. F. field shell loses about 10 per cent. of its spin at 3,000 yards, and about 20 per cent. at 5,000 yards.

The reasons for this are as follows:

I. Part of the spin is expended in overcoming the surface friction of the shell against the air. It must be remembered that the shell is constantly passing through a wave of air compressed by its own forward motion. As may be seen from spark photographs, this wave of compression extends beyond the shoulders of the shell and a considerable distance down the body. The friction caused by the shell rotating in this compressed air is much greater than it would be in air at the normal pressure.

II. Part of the spin is expended in giving the lateral drift to the shell. Suppose a shell drifts two degrees at 4,000 yards, it will have moved 400 feet laterally in 10 seconds, its mean lateral velocity will be 40 fs., and its final lateral velocity 80 fs. If the shell weighs 15 pounds, the energy consumed in giving it a lateral velocity of 80 fs. will be $\frac{15 \times 6{,}400}{15 \times 6{,}400/64.4}$, or nearly 1,500 foot pounds. How much of this is at the expense of the forward velocity, and how much at the expense of the spin, it is difficult to say.

III. When the shell rotates eccentrically, and is noisy in flight, the spin has to do a considerable amount of work in setting air-waves in motion. Theoretically, therefore, a noisy shell should drift less than a steady one, since it loses its spin earlier. But the flight of a noisy shell is usually so erratic as to render it difficult to test this point.

IV. If a shell were fired in vacuo, it would maintain its original angle to the horizontal all the way, and would come down on one edge of its base, since there is nothing to make it change its direction. When it is fired in air, its cylindro-conical shape keeps it more or less point first all the way,

at least for flat trajectories. Now it requires a considerable effort to change the direction of the axis of the rotating body, and this effort is exerted partly by the forward motion of the shell, partly by its spin, reacting on the cushion of compressed air surrounding the shell. It is not therefore surprising to find that a howitzer shell fired at a high elevation and long range has but little spin left at the end of its flight, since if fired at 45 degrees the axis of rotation has been deflected through more than a right angle.

PART IV

SHRAPNEL

SHRAPNEL

Description.—The most important projectile of the light artillery is the shrapnel. In the lecture on the subject of Corrector the manner of securing the maximum effect of shrapnel is fully discussed. Here let us see what that effect is.

A full description of the mechanical features of the shrapnel is given in the Handbook of the 3-inch Field Artillery Material. Suffice it to say here that the case is of drawn steel with solid base. The mouth of the case is closed by an aluminum head screwed in and tapped to take the service combination time and percussion fuse. The bursting charge is 2¾ ounces of loose black powder; it is placed in the base, and covered by a steel diaphragm. The diaphragm supports a steel central tube, which extends forward through the aluminum head to the fuse, and thus affords a conduit for the flames to the bursting charge. At the lower end of the central tube a stopper of dry guncotton is fitted, to prevent the loose powder charge from getting into the tube, and also to help the ignition of the bursting charge.

The shrapnel filling is composed of 252 balls, each .49 inch in diameter and approximately 167 grains in weight or 42 to the pound. The balls are assembled around the central tube and rest upon the steel diaphragm, the interstices containing a smoke-producing matrix. This matrix serves not only to hold all the parts securely in place, but, on explosion, makes a clearly visible burst and so facilitates observation of fire.

Bursting of Shrapnel.—The weakest cross-section is at the line of attachment of the head, therefore, when the shrapnel bursts the balls are expelled forward and downward with increased velocity, and as they have at the same time the

movement of rotation of the projectile they are dispersed more or less to the right and left. The case and fuse fall to earth about 25 yards from the point of burst and serve as small solid shot. The paths of the pellets form a cone, called the cone of dispersion, about the prolongation of the trajectory. This cone approximates that which proceeds from a garden-hose sprinkler. If the nozzle of the sprinkler, which may be considered as the shrapnel case, is held in a horizontal position, it is obvious that more ground will be watered than if the nozzle is inclined downward. And so, if the shrapnel is moving more nearly horizontally, as at short ranges, than vertically in its fall, as at long ranges, more ground will be searched by the pellets. It is also evident that if the nozzle be held high in the air a larger surface will be sprinkled since the spray has more time to spread out before the water strikes the ground.

Cone of Dispersion.—The section of this cone where it is intersected by the ground is an irregular oval, its dimensions varying, as is evident, with the angle of fall, the height of burst, and the relation between the velocities of translation and rotation at the moment of burst.

The greater the velocity of translation the greater will be the velocity of the pellets and consequently the longer the oval in the direction of translation.

The greater the velocity of rotation the greater the lateral dispersion of the pellets, which increase the width of the oval, the pellets traveling further at right angles to the trajectory before they strike the ground.

The width of the cone of dispersion is about 20 yards for all ranges. Hence the guns of a battery are spaced 20 yards apart.

Effective Zone.—It is assumed that when a shrapnel ball has an energy of 58 foot-pounds it has sufficient force to disable a man, and with 287 foot-pounds of energy it will disable a horse. These energies correspond in the service shrapnel bullet to velocities of about 400 and 880 foot-seconds. An increased velocity of from 250 to 300 feet is imparted to

the balls by the bursting charge. Knowing the velocity of the projectile and the weight of the balls the space within which the balls will be effective may be determined for any range.

While the service muzzle velocity is 1,700 fs. the remaining velocity of the shrapnel at 6,500 yards is only 700 fs. It is seen, then, that the remaining velocity decreases as the range increases, and so necessarily the resultant velocity of the pellets decreases as the range increases. This decrease in velocity, added to the effect of a large angle of fall which tends to tilt the nozzle downward, accounts for the shallow depth of the cone of dispersion at long ranges.

The loss of velocity and the inclination of the nozzle, so to speak, at long ranges are compensated for somewhat by increasing the height of burst as the range increases. The most effective pattern cannot however be maintained by this means. The compensation is only partial. A simple well-adjusted shrapnel covers effectively an area 200 yards in depth up to 3,000 yards. Beyond this range the depth diminishes until at 4,500 yards the beaten zone is but 125 yards deep.

Point of Burst and Interval of Burst.—The best point of burst for a shrapnel is assumed to be that point from which the burst of the shrapnel will produce practically one hit per square yard of *vertical* surface at the target. It is determined from the cone of dispersion by finding the vertical section which cut through the cone will contain as many square yards as there are pellets in the shrapnel. The distance in front of the target at which the burst occurs is called the interval of burst. On account of the variations at different ranges in the velocities of translation and of rotation the interval of burst which will produce one hit per square yard of vertical surface at the target varies with the range, decreasing as the range increases.

Practically it is found best to consider the height of burst rather than the interval of burst, since the battery commander can more readily estimate the height than the interval. Suit-

able cross-hairs in the field of the battery commander's telescope facilitate this estimation.

In our service a height of 3-1000 of the range, called 3 mils, is adopted as the most favorable mean height of burst. The point of burst at this height gives, over a large part of the range, very approximately the correct interval of burst. For short ranges this height of burst is excessive, and for long ranges it is insufficient.

The following table shows for the 3-inch shrapnel the results obtained at different ranges from bursts at the correct interval of burst, and also at a height of burst of 3 mils. The front of target that should be covered depends upon the number of balls in the shrapnel. For the 3-inch shrapnel with 270 bullets, a former model, the front to be covered with one hit per square yard is 18.5 yards.

Range.	One Hit per Sq. Yd.		Height of Burst, 3 Mils.	
	Interval.	Front Covered.	Interval.	Front Covered.
Yards.	Yards.	Yards.	Yards.	Yards.
1,000	81.4	18.5	118.2	27.0
2,000	73.0	18.5	83.4	21.2
2,500	68.98	18.5	73.5	19.55
3,000	65.84	18.5	66.6	18.76
3,500	63.28	18.5	60.9	18.84
4,000	61.07	18.5	56.4	17.12
4,500	58.97	18.5	51.3	16.13

It will be observed that between 2,000 and 4,500 yards the height of burst of 3 mils gives approximately the desired density of fire at the target. At ranges less than 2,000 yards the front covered is largely increased and the density of fire therefore diminished.

The figures refer to a single shrapnel bursting at the mean point of burst. In a group of shrapnel the bursts above and

below the mean point would largely make up the discrepancies in distribution and density.

On account of errors of gun and fuse the dispersion of several rounds is also a little greater. Experiments have shown that volley fire, two or more rounds per gun, will cover a beaten zone about 250 yards deep at 3,000 yards range, and 150 yards deep at 4,500 yards.

While it is possible, then, to deliver an accurate fire at a range of 7,000 yards, the effectiveness of shrapnel fire diminishes with the increase of the range from 3,000 yards on. At extreme ranges the possibility of putting permanently out of action an opposing battery, concealed from view and having its personnel protected by shields, is very remote.

The battery may be temporarily silenced or forced to slacken its fire, but during the calm after the squall its power will be found little impaired, for at such ranges the shrapnel has very little sweeping power and consequently the danger space is small. It must almost light on an object to injure it.

Experimental Tests.—Experimental firing in 1906 established the following facts concerning accurately adjusted shrapnel fire (3 mils height of burst) at a range of 3,000 yards:

19% of the shrapnel will burst on graze.

20% will burst less than 9 yards in front of the target, all of which distance is danger space for men standing.

50% will burst less than 66 yards from the target; danger space, 45 yards.

75% will burst less than 111 yards from the target; danger space, 84 yards.

95% will burst less than 163 yards from the target; danger space, 103 yards.

95% will burst less than 190 yards from the target; danger space, 118 yards

99% will burst less than 242 yards from the target; danger space, 149 yards.

From these figures it may be determined what area in front of an objective point is searched by well-directed shrapnel fire. There will be premature bursts much further from the target than shown by the foregoing figures which would endanger the advance of troops being supported by the fire.

The interval between the point of burst of a shrapnel and the target is called the interval of burst. It is plus (+) or minus (−) according as the shot is over or short. The distance of the normal burst from the target is the mean interval of burst, and depends upon the range, and, therefore, the height of the mean burst.

The following facts have also been ascertained by experiment.

The time fuse acts with a considerable degree of uniformity. The error of the fuse is, however, much too great. At mid-ranges about 20% of the shrapnel fired will burst on graze even though the fire has been well adjusted. They are then, as a rule, quite ineffective. Moreover, about 10% to 15% will burst so high as to be almost ineffective. Thus, due to the error of the fuse, about 30% of the fire is practically ineffective at favorable ranges and 30% of the ammunition is wasted by reason of a defect in one part of the projectile.

Artillery efficiency is measured by its ability to burst effective shrapnel at the target, and for this purpose the whole expensive plant in men, animals and material is maintained. Assuming that the personnel is capable of performing its part perfectly, the measure of efficiency would still depend upon the accuracy of the fuse. The fuse is the weak point in the present system. The "hooded-vent" fuse, with a reducer error, has been adopted since the tests of 1906; but the error is not much less than that of the earlier type, and the foregoing figures are practically live.

About 5% of the shrapnel cases burst in air.

Shrapnel seldom break up in the gun or burst at the muzzle.

About ⅓ of the pellets are ineffective at all ranges.

The normal height of 3 mils gives the most favorable distribution of effect, when targets of all kinds are considered, that is, the density of fire approaches most nearly to one hit per unit of surface.

A lower burst gives very dense effect over a restricted area, but the bullets are not used economically; two or three being expended to do the work of one.

A greater height of burst increases the width and depth of the bullet pattern, and permits utilizing the full effective range of the bullets; but the density of fire decreases, and the proportion of ineffective hits increases very rapidly with the height of burst. Hence, the area is not effectively searched. It is to be noted, however, that against deep, broad targets it is preferable to have the mean height of burst a little high rather than too low, as the former gives a better distribution of the effect.

Bursts on graze are practically ineffective unless within 10 yards of the target.

The projectile will ricochet up to 3,700 yards and burst after graze is obtained. At longer ranges the projectile does not seem to ricochet, but enters the ground and bursts after penetrating several feet, creating a large crater. There were instances in the Russo-Japanese War of shrapnel penetrating 9 inches of masonry before bursting.

High Explosive Shrapnel.—A more powerful shrapnel than the one now in general use in our service is being perfected. It is known as a single-type projectile, that is, it is designed to be used either as a shrapnel or as a high explosive shell. This is accomplished in the following way: The matrix in which the pellets are imbedded, instead of being an inert substance, or merely a smoke-producing material as in the common shrapnel, is, in itself, a high explosive. This high explosive, however, is very insensitive, so that, when the shrapnel is discharged in the air by the burning of the small black powder charge in its base,

the high explosive is not detonated or exploded. In order to cause the detonation of the matrix when the projectile bursts on percussion, the head of the projectile has a chamber containing a charge of high explosive. When the projectile strikes a resisting object, the percussion element of the combination fuse detonates the charge of high explosive, which, in turn, detonates the high explosive matrix. If the projectile bursts in air the head is blown off, and on striking acts as though it were a small high explosive shell.

This projectile, if perfected, will possess many advantages, as the difficulties growing out of several types of ammunition would be eliminated and the vexing question of the relative proportions of shell and shrapnel would no longer present itself.

High Explosive Shell.—At present, shrapnel and shell are both issued, the former for animate and the latter for inanimate objects. The present shrapnel bullet has not sufficient power to destroy material; and on account of the flatness of the trajectory and the small angle of the cone of dispersion, it cannot reach troops in any but the lightest entrenchments. Hence, the other type of ammunition, or the steel shell, is issued, holding about two pounds of the service high explosive. This is burst by a detonating percussion fuze.

On detonation of the filler, the shell breaks up into 500 to 600 fragments, and it has been proposed to use it instead of shrapnel against troops in entrenchments, for if it bursts at the proper point, by means of a time fuse, the fragments fly in all directions and search cover in a manner impossible to shrapnel. No satisfactory results of this nature have been obtained, however, and so no time-shell is issued in our service.

The explosive used in the H. E. shell is a secret compound, and combines extreme safety in transportation with extreme certainty and force of action. The shell complete weighs the same as the shrapnel, 18.75 pounds. The projectile in each case weighs 15 pounds; the high explosive power of the shell compensating for its lightness in metal.

PART V

PRACTICAL GUNNERY

Chapter I. Fire and Fire Data.
" II. Indirect Fire and Deflection.
" III. Range and Ranging.
" IV. Angle of Site.
" V. Corrector.
" VI. Observation of Fire.
" VII. Position and the Mask.

PRACTICAL GUNNERY

CHAPTER I

FIRE AND FIRE DATA

The Sheaf of Fire.—When the fire of a number of guns is directed upon any object the line of fire of each gun forms with the others a bent cone, called the sheaf of fire. Due to the varying inaccuracies of the gun it is practically impossible to cause all the projectiles to light at the same point. Each battery salvo, therefore, searches a slightly different area from the other, which is beneficial rather than undesirable.

A battery may be likened to the human hand, in that the sheaf of fire, represented by the fingers, may be shifted to the right, left, up or down, by the movement of the wrist, or the sheaf may be opened out, closed, or maintained at the parallel, by the movement of the four fingers. It is the ability to shift the sheaf of fire rapidly, and direct the fingers, so to speak, at the target, that constitutes a skilled gunner. When this can be done with speed and accuracy, under the varying circumstances encountered in the field, a battery is capable of delivering an effective fire. If this cannot be done, the hand is paralyzed, and so the battery cannot perform its function.

When a man points his forefinger at an object, the mind controls the movement. The muscular movement of the hand and arm is more or less involuntary. It is not necessary to concentrate the mind upon the movement of the arm and

hand, but only upon the object. And so it should be in the case of a battery commander in directing the sheaf of fire. The calculation of the necessary data should be a matter of second nature with him to such an extent that the most unexpected developments will not disturb the habit of his mind and thereby destroy the sheaf of fire.

Fire Control and Direction.—The officer who has charge of the auxiliary arm of artillery is said to "control" the fire. Under his authority as the controlling officer he generally assigns a certain portion of the hostile terrain to a group of guns. That portion so assigned a particular group is said to be its sector of fire. The officer in command of the group "directs" the fire of his guns within the sector assigned him. There may be a number of hostile positions within any sector. If any of these positions are occupied by groups of artillery, the one aim of the officer directing the fire is to secure a superiority of fire over the hostile guns. This may be frequently done even though the number of his guns is less than that of the enemy. For instance, the directing officer may have a much more perfect knowledge of the hostile position than the enemy has of the firer's position. In such a case he may shift the sheaf of fire of all his guns from one hostile position to another, alternately subduing the enemy's fire, whereas the hostile fire is scattered and more or less ineffective, due to the enemy's ignorance as to the exact position of the opposing guns. The method of delivering a rapid fire in sudden bursts of short duration is called the "Squall Method," and is obviously more effective than the old method of prolonged fire at a slower rate. It is also more economical in the expenditure of ammunition.

If a battery or group open with inaccurate data, its position is at once exposed to a watchful and well-informed enemy, and before the fire can be adjusted a weak opponent will withdraw to a new position and open fire, or a relatively strong opponent will attain superiority.

The necessity of obtaining accurate data before opening fire is quite apparent, for the enemy, once having attained the ascendancy, will render its opponent ineffective altogether or force a change of position on the latter's part.

It is often advisable to adjust the fire upon a position somewhat removed from the one to be eventually attacked, and then to suddenly shift the adjusted sheaf upon the hostile position. This eliminates the danger of alarming a weak opponent, who may be successfully destroyed, and in a measure prevents the disclosure of position to a more worthy opponent.

Now in order to be able to direct the fire, and shift the sheaf from point to point, it is necessary to become thoroughly familiar, not only with the practical means employed, but with the theory upon which the practice is based.

Inaccuracy of Fire.—However perfectly a gun may be laid, it is practically impossible to get two successive rounds to fall in the same place. This is due to several causes. In the first place, the muzzle velocity varies from round to round, owing to irregularities in the powder charge and its combustion, and in the resistance of the driving band. Next, the varying jump of the gun causes deviations in elevation. And if the carriage be on a lateral slope, or if one wheel be on bad ground, the jump causes errors of direction as well. In the next place, the projectile rarely comes out of the muzzle quite straight, but usually with its nose pointing somewhat away from the line of departure, and revolving around it. This causes the projectile to describe a corkscrew-curve around the actual trajectory. The amount of the wobble tends to decrease under the influence of the resistance of the air, till at about 1,000 yards the projectile begins to settle down to a regular curve. In the same way a spinning top, after a first period of wobbling, "goes to sleep," and remains steady till its spin is insufficient to resist the overturning movement due to the frictional resistance of its point.

A further important cause of inaccuracy is defective

manufacture. If the wall of the projectile be thicker at one side than at the other, the center of gravity will not be in the axis of the shell, and its rotation will cause the shell to wobble.

Besides these sources of error, the flight of the shell will be affected by the varying wind which it happens to encounter. Rough corrections in deflection for windage are prescribed in the Drill Regulations.

The practical result of the combination of errors is that the trajectories of a number of projectiles fired from the same gun at the same elevation form a bent cone (Figure 1) which is called the sheaf of fire of the gun, just as the cone of fire from the four guns is called the sheaf of fire of the battery.

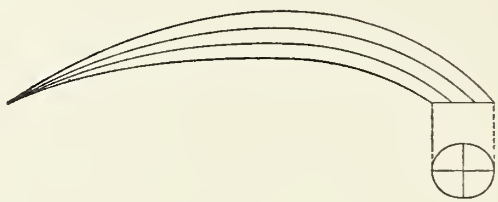


Fig. 1.

The intersection of the surface of the ground with the sheaf of fire forms an ellipse, or oval figure, of which the breadth is equal to the diameter of the cone, while the length or major axis increases with the smallness of the angle of descent.

The more accurate the gun the smaller the ellipse. The accuracy of a gun at any range is determined as follows:

A number of shots are fired under the given conditions, care being exercised to make the circumstances of all the rounds as nearly alike as possible. The point of fall of each shot is plotted on the chart or marked on the target when practicable. The target may be either horizontal or vertical.

The numerical sum of the horizontal deviations divided by the number of shots is the mean horizontal deviation.

The mean vertical deviation is similarly obtained from the numerical sum of the vertical deviations.

The actual distance of each shot from the center of impact is the *absolute deviation* for the shot, and the mean of the absolute deviations is the *mean absolute deviation of the group.*

By comparing the mean absolute deviations of different groups of shots we may arrive at the comparative accuracy of different guns or of the same gun under different conditions of loading and firing.

Since the effect of the same error is greater for long ranges than for short, it is apparent that fire at long ranges is more inaccurate than for short. Since long-range fire is not only less effective than short-range fire, but is also less accurate, we can see that the practical gunner must employ every form of ingenuity to shove his guns into close proximity to the enemy. The great mistake was made of fighting field guns at too long ranges in the Russo-Japanese War. Neuffer tells us that the use of the mask was not well understood.[1]

Percussion Fire.—Percussion fire is principally employed for the destruction of material objects, such as walls, buildings, obstacles, artillery material, etc. Such fire is termed fire for demolition. An accurate adjustment in range is requisite.

For the destruction of artillery material or other targets of low relief, light field guns should habitually be approached within 2,500 yards of their target.

The usual procedure is to obtain a 100-yard bracket and to fire enough rounds at the limits of this bracket to determine definitely that fire at the near limit is short and that fire at the further limit is over. One or more battery salvos are ordinarily required for this purpose. The bracket having been established, continuous fire is begun at the mid range of the bracket. If observation of a considerable number of

[1] Lieutenant William Neuffer, Third Bavarian (Prince Leopold) Regiment of Field Artillery. (Artilleristische Monatschefts No. 35, November, 1909.)

rounds at the mid range indicates that the mean point of burst is still short or over, the range is changed by 25 yards in the appropriate sense. Changes of range of less than 25 yards should not be made.

Percussion fire is considered adjusted when it is evident that effect is being produced upon the target and when the proportion of shorts and overs is sensibly even.

Time Fire.—Time fire is employed for the attack on animate objects. The nature of the target and the conditions affecting observation of fire determine the limits within which the range may be found.

When the target consists of troops immobilized in position —as, for example, infantry in trenches, artillery in battery, etc.—a 100-yard bracket is always, if possible, obtained.

If the conditions are favorable for observation, the exact adjustment of the fire may be at once undertaken, as explained in the case of percussion fire. Before passing to fire for effect, however, salvos are fired at the mid range of the bracket for the final adjustment of the height of burst and the distribution. The fire for effect may be by continuous fire or by volleys.

But if the conditions are unfavorable for observation, it is preferable, after adjusting the height of burst and distribution, to direct the fire for effect successively at the short, mid, and long ranges of the bracket until it can be definitely determined at which range the fire is most effective. Salvos, continuous fire, or volleys may be used for the purpose.

If a 100-yard bracket cannot be surely obtained, then the bracket obtained may similarly be searched by successive increments or decrements of 50 or 100 yards in the range until it can be definitely determined at which range the fire is most effective.

Time fire is considered adjusted when it is evident that effect is being produced upon the target; when the great proportion of bursts in air are short of the target and at the proper

mean height; when the shrapnel cases are seen to strike at or near the target; when dust, if seen at all, is knocked up by the bullets both in front and in rear of the target; and when a due proportion of bursts on graze occur and such bursts are about evenly divided between shorts and overs.

When the target consists of troops moving or liable to move, the smallest bracket is obtained which can be surely and quickly established, and its depth is then promptly searched by the subsequent fire.

The usual procedure in such cases is to obtain quickly by bold changes of range a large but unmistakable bracket; to narrow this bracket to 200 or to 100 yards if the conditions permit; to fire verifying salvos at the short limit of the bracket, if the height of burst and distribution have not already been adjusted during the bracketing series; and then to employ volleys or salvos at successive ranges, or zone fire to search the bracket.

Volleys or salvos at successive ranges may be employed to search an area of any desired depth. The range ordered for the first volley or salvo is usually that corresponding to the short limit of the bracket. The fire is then continued progressively until the opposite limit of the bracket is reached by changes of 50 to 100 yards in range from volley to volley or from salvo to salvo, the time interval between volleys or salvos being such as the officer conducting the fire may deem appropriate. A range increment (or decrement) of 50 yards is ordinarily used if a 100-yard bracket is established, of 100 yards if a longer bracket is established.

Zone Fire is especially adapted to searching quickly the depth of a 200-yard bracket. It is not employed for lesser depths. If the depth to be searched is much greater than 200 yards, a second rafale is fired to extend the effect in depth. The initial range of a rafale of zone fire is usually taken as 100 yards less than the short limit of the bracket; but if the target is obviously moving away from the guns, or if, in the

attack of a stationary target, it is perfectly clear from the lay of the ground that fire short of the short limit of the bracket would be wasted, then the short limit of the bracket may be taken as the initial range.

If the ground to be searched has a noticeable slope either to the front or rear, and indirect laying is to be employed, the angle of site will vary for different parts of the area to be searched.

In the case of zone fire a mean value of the angle of site is taken, and a corrector is used which will give low bursts at the near limit of the zone if the slope is away from the guns, and bursts slightly above the normal height if the slope is toward the guns.

In the case of volleys or salvos at successive ranges the same procedure may be employed if the area to be searched is not deep and the slope not great; but for searching long and steep slopes it is usually preferable to take the angle of site and then to vary the corrector from volley to volley or from salvo to salvo, increasing it if searching up the slope, decreasing it if searching down the slope. A change of two points in the corrector from volley to volley or from salvo to salvo will suffice in the usual case.

Whenever searching fire is employed it must be carefully observed with a view to securing a closer adjustment for subsequent fire. If fire at certain ranges is evidently ineffective, those ranges are rejected in the subsequent fire. If the conditions permit, the process of bracketing is resumed and a closer adjustment secured.

If the ground either in front or in rear of the target cannot be seen, or if the target is totally masked, every effort must be made to determine as accurately as possible the distance of the target from some feature of the terrain which is visible to the officer conducting the fire, and which may be used as a registration mark for the adjustment of fire. Thus if a target is beyond a crest the distance of the target from the crest line

is to be determined; if the target is masked by trees and is so situated that the ground in rear of the target can alone be seen, some feature of the ground in rear of the target may be taken, as the registration mark and the distance determined from it.

In such cases the fire is adjusted on the registration mark chosen and then shifted so as to search the area within which the target has been located. It is most important to have observers posted so that they can observe the fire and assist in its adjustment.

Verifying Salvos.—Salvos fired to verify the firing data in use, or to secure a more perfect adjustment of the fire before passing to fire for effect, are termed verifying salvos.

They are especially appropriate to fully establish the limits of a bracket; to determine definitely whether fire at a given range is really effective, as has appeared from the observation of previous but insufficient fire; to secure the final adjustment in direction, height of burst, and range, particularly in cases when only a portion of the guns have been used in the fire for adjustment.

If opportunity is afforded during the bracketing series to secure a satisfactory adjustment of the fire, verifying salvos are unnecessary, except that, in the case of a target moving toward or away from the guns, if any considerable time has elapsed since the establishment of that limit of the bracket toward which the target is moving, a salvo or salvos should be fired at the range corresponding either to that limit or to a point still farther in advance of the movement of the target for the final verification of the range before passing to fire for effect.

Application of Fire.—In service the fire of artillery must be adapted to meet the requirements of many and ever-varying conditions. An infinite variety of concrete problems is afforded, and each problem will have its own best solution. Great flexibility in the employemnt of fire is hence called for.

The Regulations set forth principles which are the bases of action and rules which may serve as guides in the average case; but the Regulations must not be looked to for ready-made solutions of the problems which arise in service. Having thoroughly mastered the principles of the Regulations and thoroughly grasped the possibilities of the gun and its equipment, an officer must so prepare himself that he will be able to recognize at once the means to be employed in any concrete case and be capable of putting these means into effect. Every latitude is allowed him in the choice of a method of fire and in its adaptation to the special case in hand. By constant practice in peace in employing fire (simulated or otherwise) to meet the requirements of a great variety of tactical situations, officers may prepare themselves to use their guns to the best advantage of war.

The special characteristics of the different methods of fire provided for in the next text are outlined below, with some illustrations of their applicability.

Continuous Fire is adapted especially to the demolition of material objects and to the attack of personnel inactive and more or less fixed in position and protected from fire.

The fire may be as rapid or as slow as desired, thus permitting the expenditure of ammunition to be exactly regulated to meet the requirements of the case.

Exact adjustment in range is sought; but if the conditions of observation are such as to preclude this, the smallest possible bracket is obtained and its depth searched by successive changes in the range.

Volley Fire is adapted especially to the attack of personnel that are more or less vulnerable. The special characteristic of this method of fire is its great flexibility. The number of volleys to be fired; their range difference (if any), the number of rounds in each volley, are all in the hands of the officer conducting the fire. By suitable manipulations of the sheaf he may readily shift the fire from point to point of the terrain

as necessity may require, and by adapting the bursts of fire to meet the crises of the action he may utilize the ammunition to the best advantage.

If exact adjustment in range can be obtained, volleys at a single range are employed; otherwise volleys at successive ranges are used.

Salvos are adapted especially to securing the adjustment of fire. They may also be used for producing effect, and especially with the idea of obtaining at the same time additional information on which to base a more exact adjustment of the fire. They are employed at single or successive ranges, according to the principles of volley fire.

Zone Fire is adapted especially to the sudden attack of troops moving or liable to move. The special characteristic of this method of fire is that it provides for searching a deep area with the utmost rapidity, and thus of striking the enemy before he can escape from that area. IT IS USED ONLY FOR THE ATTACK OF IMPORTANT BODIES OF TROOPS WHO MUST BE STRUCK AT ONCE, IF AT ALL.

A 200-yard bracket is sought, and the rafale is usually commenced at a range 100 yards less than the short limit of the bracket. Great density of fire is thus obtained over the full depth of the bracket.

Fire at will is employed solely for the close defense of the guns from hostile attack. If the distant approach of the enemy is seen, then he is met by volleys, the range being successively decreased in accordance with his rate of advance and the fire being held under rigid control until the last moment; but when it is seen that a rush for the guns is imminent, fire at will should be ordered.

Against infantry in position and more or less protected by entrenchments the fire should be carefully adjusted. As our infantry advances to the attack the intensity of the fire should be regulated to suit the necessities of the case, being slow or ceas-

ing entirely while the enemy is concealed or inactive, rising to great intensity when the crises of the action develop and the enemy exposes himself to meet them. Continuous fire is indicated for the ordinary phases of the action, volleys for the crises, the object being to assist our own infantry; by inflicting as much damage as possible upon the enemy; by destroying his morale; by forcing him to keep under cover; and by preventing effective fire upon his part.

It is obviously advantageous to employ direct fire in repelling an infantry attack, certainly in its final stages. This will be quite impossible, however, in many cases, if the hostile artillery is superior. If such an attack is foreseen, the guns to be employed to repel it should be well placed and thoroughly masked in advance, otherwise their fire will be silenced, whereas if their position is not disclosed they will be able to play upon the advancing infantry while the hostile artillery is searching for their position. The final stages of an infantry attack are usually of such short duration that it will either be repulsed or succeed before much searching can be done by the enemy in the endeavor to locate the exact position of the guns.

It was frequently found impossible in Manchuria to employ indirect fire against the rapid advance of attacking infantry with any degree of effect. Very often the Japanese reached the Russian trenches before the guns of the latter could open upon them from an indirect position. Hence the Japanese claimed that direct fire should be used to repel attack and indirect fire in the preparation for an attack.

Against artillery in position the first object is to gain the ascendancy over it by inflicting as much damage as possible upon the personnel. Immediately effective fire is particularly demanded if the enemy can be attacked at a disadvantage, as, for example, while limbering, or unlimbering. Obtaining a bracket as small as possible, searching the depth of the bracket, carefully observing the fire and securing as promptly

as possible an accurate adjustment are the means to be ordinarily employed in attacking the personnel.

Due to the difficulty, however, of reaching effectively the personnel of batteries provided with shields and posted in masked or semi-masked positions, the struggle between evenly matched artilleries will often be long drawn out. If the enemy's artillery is temporarily overmatched, it may suspend its fire and shelter its personnel; but it must be expected to renew the struggle as soon as the pressure upon it is relieved. The aim must be to gain the superiority of fire by suitable concentrations of effort on the part of our own artillery; the opportunity may then be gained to destroy the enemy's material by well-adjusted shell fire.

A slowly moving target such as infantry, or mounted troops impeded in their march, may be quickly bracketed by salvos and then attacked by searching fire.

Infantry in march formation may be thus attacked, but immediate deployment on their part is to be anticipated, and the officer conducting the fire should be prepared to reach them, probably behind cover, with a well-distributed fire.

Infantry moving to attack in deployed lines or in line of small columns may be met by volleys successivly reduced in range as the infantry approaches. If their formation is in line of small columns the fire should be distributed so that a piece or platoon may bear upon each of the small columns.

At close ranges infantry will probably endeavor to advance by successive rushes from cover to cover. Such rushes may be met by volleys previously prepared for upon selected positions, evidently in the immediate path of the enemy. If the positions occupied by important bodies of the enemy during the intervals of advance are well defined, accurately adjusted fire may be brought to bear upon such positions, and the ground between successive positions may be covered by searching fire when important movements of the enemy from one position to another are attempted.

In the case of a rapidly moving target, if the target is moving at right angles or obliquely to the line of fire, it is ordinarily best to adjust the fire upon some position in the path of the target and ahead of its movement and open with volleys or with zone fire as it approaches the position selected. If the target is moving parallel to the line of fire, or nearly so, the target may be bracketed and volley fire opened at that limit of the bracket toward which the target is moving, or at a lesser or greater range, the object being to bring fire to bear upon a point in advance of the movement of the target and to continue the fire until the target has passed through it. A target having been once brought under effective fire, its subsequent movements may be followed by volleys varying in range and direction, according to the rate and direction of march of the target.

Designation of Objectives.—Targets and aiming points must be designated in a concise and unmistakable manner. Officers must exercise themselves in describing objectives of all kinds, in all available forms of terrain, and must accustom those under them to the terms and methods employed in the description. Practice of this character should habitually form a part of firing instruction, and should also be included in the instruction of scouts, agents, and range finders.

If the targets are distinct and clearly defined, they may be designated by name, as, for example, "The battery on hill 1,240," "Cavalry to the right front," etc. But if the target is indistinct and poorly defined, or if it is masked, then each unit may be assigned so many mils of a given front to attack.

In designating objectives of any kind (targets, aiming points, registration marks, etc.) the following procedure is appropriate, especially when the objective is not conspicuous nor readily recognized:

Define the relative position of the objective and its characteristics. The relative position is fixed by giving the approximate direction and distance of the objective and its situation

with respect to prominent features of the landscape. The characteristics usually important are the nature of the object, its shape and color.

If the objective is in itself inconspicuous, then it is usually best to first designate the most prominent object in its general direction, give the angular distance between this auxiliary objective and the real objective, and then describe the latter as before.

The usual method of procedure is as follows:—

1. Indicate the general direction of the objective.

2. Designate the most prominent object in the zone indicated.

3. State the angular distance from this auxiliary object to the objective.

4. Designate the objective.

Thus:

1. To our right front.

2. At 3,000 yards a large stone house, square, two-storied, with a cupola on top.

3. 500 mils to the right of the cupola.

4. At 2,500 yards a battery of artillery in position in rear of the large orchard.

Or:—

1. To the left rear.

2. At 4,000 yards a line of hills with three plainly marked and well-wooded valleys.

3. 350 mils to the left of the left valley.

4. On the sky line of the hills, a lone tree, low and bushy.

Or:

1. Straight to the front.

2. At 3,500 yards a farmhouse in a grove of trees on a ridge.

3. Commencing at 500 mils from the left-hand tree of the grove.

4. Cover 100 mils of the crest line.

Targets and aiming points are preferably designated by word of mouth and to a person standing near by. On the occupation of a position the aiming point and the expected targets should, as far as practicable, be thus pointed out to the officer commanding the guns.

If it is necessary to send this information to a person at a distance, it is important to remember that objects often present very different appearances if viewed from widely separated positions. For this reason it is desirable to select as aiming points objects having a uniform outline, and hence presenting the same appearance from whatever angle they are viewed. The information is transmitted by couriers or telephone. If a courier is used, he is required to keep the objective in view as much as possible while passing from one station to the other.

The designation of objectives may be greatly facilitated by causing a panorama sketch of the terrain to be prepared and copies to be furnished the different subordinate commanders concerned. On such a sketch important landmarks and military objectives should be named or numbered, so that they may be readily referred to.

Observing the Terrain; Sectors of Observation; Forming the Sheaf; Preparation for Firing.—In preparation for definite and imminent phases of an action, certain bodies of artillery may be ordered to observe the enemy in designated portions of the terrain and be ready to bring him under immediately effective fire.

If possible, the position of the enemy is clearly pointed out; but if his exact position within a certain area has not been determined the area may be divided up into sectors and a sector assigned to each important group of artillery. In the former case the firing data are determined for the known position of the enemy; in the latter case, for prominent features of the terrain within the sector assigned.

With a view to gaining readiness for instant action, the guns may be laid upon the target or upon some selected feature

of the terrain and the sheaf formed so as to provide for the desired distribution.

To form the sheaf, an aiming point is selected, a deflection is given the right piece which will cause it to be directed upon the right section of the target, or upon the registration mark, and a deflection difference is employed which will suffice to distribute the fire over the known or expected front.

If the position of the enemy is known and all necessary data have been obtained, the pieces may be at once loaded.

If the exact position in which the enemy will appear is not known, then on his appearance the necessary corrections in range and direction must be quickly estimated (or measured) and set off. The correction in range is obtained by estimating the target's distance from the selected registration marks; the correction in deflection by measuring, by means of hand-breadths or the B. C. ruler, the angle from the registration mark to the section of the target which is to be attacked by the directing piece. The circumstances of the case must decide whether the pieces are loaded before the target appears.

At a mean range (about 3,000 yards) a battery may be expected to cover effectively a front of about 30 mils if parallel fire is used.

The initial opening of the sheaf depends upon the nature of the expected target and the circumstances of the action. Thus, if the enemy's artillery is the expected target a parallel formation of the sheaf may be preferable, while if lines of infantry are to be attacked a more open formation may be appropriate.

If, in order to assist our own infantry, the artillery is called upon to repress the activity of a long line of hostile infantry in position, each battery may be required to act over a wide front. Good judgment and great versatility in the employment of fire are called for under such circumstances, in order that the desired results may be obtained without undue expenditure of ammunition in the earlier phases of the attack.

Means may be employed to keep the entire hostile line under the menace of fire, single guns being freely used to repress special activity of the enemy in the sections assigned to such guns.

Registration of Fire.—Artillery already in position may take advantage of lulls in the progress of an action to register its fire upon positions in which an enemy is known to be or in which he is expected to appear. The nature and circumstances of the action determine the relative importance, on the one hand, of securing this information, and, on the other, of keeping concealed the position of our own artillery.

The purposes of fire for registration are:

(a) To determine the firing for reaching certain prominent features of the terrain, such as crests, edges of forests, villages or cultivated fields, houses, etc.

(b) To discover by actual fire the accidents of the ground which might conceal the enemy or hide the points of burst of our projectile.

(c) To thus gain the ability to open immediately effective fire upon a target appearing at or near these prominent features of the terrain.

Registration of fire is especially appropriate for artillery to which definite sectors of observation have been assigned, as the necessary firing data may thus be most readily obtained.

If the position of the enemy within the sector is definitely known—as, for example, that he is behind a certain crest or in the edge of a certain piece of woods—the fire is directed upon some prominent landmark at or near the enemy's position as the registration mark, and the data thus secured in advance for opening prompt and effective fire.

If, however, the enemy's position within the sector has not been located, the artillery commander proceeds in a systematic way to secure the data which will enable him to reach promptly and effectively any part of the sector. He studies the terrain, decides upon the limits in width and depth of the area to be

registered, notes the specially prominent features of the terrain within these limits, and by actual firing directed upon these natural features secures the data which will enable him to reach promptly any target appearing in their vicinity.

Fire Data.—Fire is classified as direct and indirect according to the method employed in laying the piece and sights.

When the target is clearly visible through the sights the method of sighting the piece is direct. This method is called direct laying.

When an obstacle intervenes between the sights and the target, such as a hillside, the sighting of the piece must be indirectly done, and this method is called indirect laying. The intervening obstacle is called a mask, which will be discussed later.

Whichever method is employed, it is necessary:

1. To so direct the axis of the gun that the projectile will pass in the direction of the target. (Deflection.)

2. To so elevate the axis that the projectile will reach the target. (Range.)

3. To so regulate this elevation that the trajectors will pass through the target whether above or below the piece. (Angle of sight.)

4. To cause the projectile (if shrapnel is used) to burst where it will give the maximum effect. (Corrector.)

For direct fire, each gunner sets his sights at the prescribed elevation and deflection, and aims his gun as he would a rifle. The only other instrument the use of which is involved is the fuse setter in case of time shrapnel fire. The firing data for direct fire, then, are:

1. Deflection. (Wind and drift.)
2. Fuse setting.
3. Range.

Indirect fire involves more details which appear at first sight more troublesome, principally by reason of the fact that all angular measurements are computed in mils, a technical

unit which is really a definite fraction of a degree. Before going into the subject of Indirect Laying, it is essential that the mil be thoroughly understood.

A mil is an angle. It corresponds in form to a degree and not to lineal measures as feet, yards, etc. It is that angle which a tangent equal to 1/1,000 of a radius will intercept at the center of a circle.

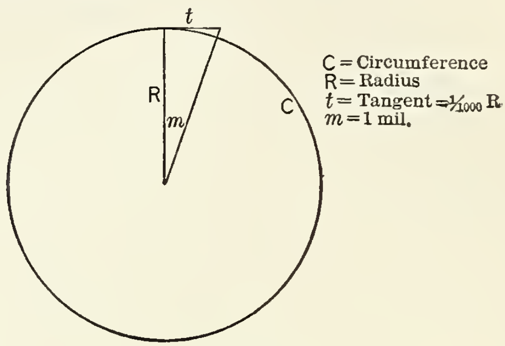


Fig. 2.

A tangent is a straight line perpendicular to the radius at its intersection with the circumference of the circle. (Figure 2.)

Now it has been found that in any circle there are approximately 6,400 mils.

Since there are 360° in a circle:

Circle	360°	=	6,400 mils,
Straight angle	180°	=	3,200 mils,
Right angle	90°	=	1,600 mils,
	45°	=	800 mils.

All calculations, as has been said, must from now on be made in mils. It is readily seen how adaptable the unit is both to horizontal and vertical measurements, for if a mil is that angle which is intercepted at the center by a tangent equal to 1/1,000 of the radius, so the tangent which a mil will subtend at any range is equal to 1/1,000 of that range as illus-

trated in the figure. At any range the front of the target is taken as the tangent to a circle of which the range is the radius.

In order to determine, then, what number of yards a mil subtends at a given range, it is only necessary to divide the range by 1,000. (Figure 3.)

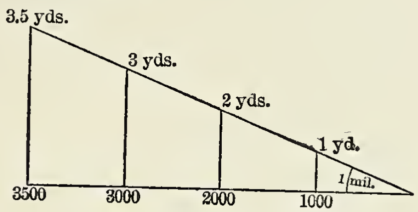


Fig. 3.

Thus	1 mil subtends	1 yd.	at	R	1,000,
	10 mils subtend	10 yds.	at	R	1,000,
	1 mil subtends	2 yds.	at	R	2,000,
	20 mils subtend	40 yds.	at	R	2,000,
	50 mils subtend	250 yds.	at	R	5,000.

Before proceeding further, it must be understood that the sum of the angles of any triangle = 180°.

But 180° = 3,200 mils.

∴ The sum of the angles of a triangle = 3,200 mils.

Also that vertical angles are equal. (Figure 4.)

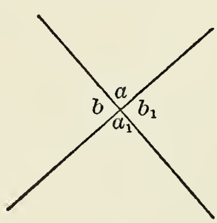


Fig. 4.

a and a_1 are vertical angles and so also b and b_1.

$$\text{In Figure 5, } x + 90° + a = x_1 + 90° + a_1$$
$$a = a_1 \text{ (vertical angles)}$$
right angles are also equal.
$$x = x_1$$

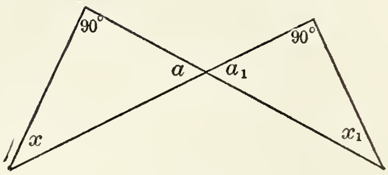


FIG. 5.

It should also be understood that the square of the hypotenuse is equal to the sum of the squares of the other two sides of a triangle. The hypotenuse is the side opposite the right angle. (Figure 6.)

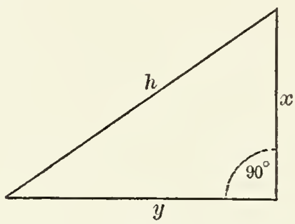


FIG. 6.

$$h^2 = x^2 + y^2$$
$$x^2 = h^2 - y^2$$
$$y^2 = h^2 - x^2$$

This rule is called the Pons Asinorum; so named from the similarity of the geometrical figure to a bridge, and the difficulty many beginners experience in getting over it; hence *pons asinorum*—the asses' bridge. And here it may be said that it would be foolish indeed to attempt to cross to the next chapter without a thorough grasp of the meaning of the term mil. It is easy to remember if we recall its derivation from the Latin word *mille*, meaning thousand.

CHAPTER II

INDIRECT FIRE AND DEFLECTION

Indirect fire involves many details which only constant practice and study will master. It is possible for a gunner to deliver an effective direct fire without much knowledge of gunnery, for he may be as skillful in estimating the range and in the mechanical adjustment of sights and fuse setter as the most learned artillerist. Before proficiency and effectiveness may be attained in indirect fire, however, it is absolutely necessary that a complete knowledge of the subject be had. In fact, it would be impossible to even practice indirect firing without understanding the underlying principles of the method.

In indirect fire, it is contemplated that an obstacle intervenes between the guns and the target, the obstacle serving to mask the guns from the view of the enemy.

If the guns are behind such an obstacle with respect to the target, it is obvious that the target is not discernible from the guns. It is, therefore, necessary for the battery commander to seek a position from which he can see both the target and the guns and rapidly communicate with the men at the latter. This point of observation should preferably be on a flank of the line of guns, or directly in rear of and above them. It is called the battery commander's station.

Now it is plain that if the battery commander, from his observing station, B, Figure 1, sights his instrument at some point, P, visible through the telescopic sights of the guns, and then revolves his telescope until the target, T, is picked up,

that the horizontal angle PBT fixes the direction of T with respect to B. This horizontal angle or a is called the azimuth of the target and the point P, visible from the guns, is called the aiming point. This angle may be measured by the battery commander's telescope (see page 109, Handbook of the 3-inch Field Artillery Material, 1908), by the battery commander's ruler, (ibid., 114) or by the hand. (The last two methods will be subsequently explained in this chapter.)

Aiming Point.—Before proceeding further, it is well to dwell upon the subject of "Aiming Point." (Drill Regulations, 1908, Paragraphs 444, 445.)

When indirect laying is to be employed, the selection of a suitable aiming point calls for special attention. The aiming point should be:

1. Surely visible from the emplacement of each gun;
2. Distinctive and easily picked out;
3. At a considerable distance from the guns; and
4. Preferably near the normal to the line of guns.

If any doubt whatever exists as to the visibility of the aiming point, it is always best, before the guns come up, to go to the point where each gun is to be placed and make sure that the aiming point will be visible through the sights from that point.

Some object which quickly attracts the eye should be selected; and, if possible, it should be the only object of its kind in the vicinity, so that doubt, hesitation, and mistakes may not arise, either in the designation of the aiming point or in finding it quickly after looking away.

A distant aiming point is preferable, for the more the aiming point is removed from the guns the more are errors in calculation of parallax minimized. But it is not desirable to take inconspicuous aiming points or those at distances so great as not to be readily determinable. Usually points not less

than 2,000 and not more than 6,000 yards distant will be found most suitable.

A point in rear or in front of the guns and near the normal to their front is always to be preferred, provided it is at least 1,000 yards distant. If the aiming point must be closer than 1,000 yards, then it is best to have it on the flank.

If the distant aiming point is apt to be obscured by mist or smoke, then a secondary aiming point should be provided for. A stake may be put up for the purpose. The guns having been oriented on the target by means of the distant aiming point, the sights may, when necessary, be turned upon the new aiming point and the latter used in subsequent fire.

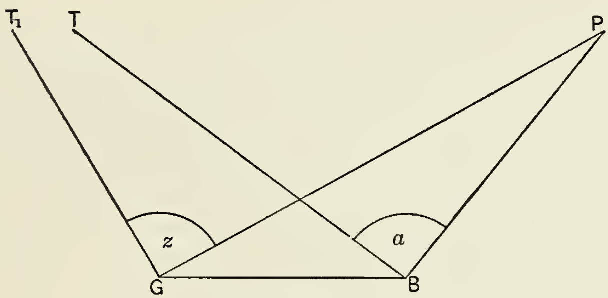


FIG. 1.

Calculation of Formula.—If the right gun, Figure 1, were aimed at P and then turned through an angle equal to a, the final direction of its line of fire would not pass through T, but through T_1, since the angle z is equal to angle a.

The necessary correction may be arrived at in the following manner:

In Figure 2 the angle D is the angle through which the axis of the gun must be turned from the aiming point to give the direction of T or the target, and is called the angle of deflection or merely the deflection of the sight piece.

In the two triangles BPX and GTX the angles at X are

evidently equal. We also know that $B+P+X = 3{,}200$ mils and $G+T+X = 3{,}200$ mils.

$$\therefore B+P+X=G+T+X$$

Subtracting X from both sides—

$$B+P=G+T$$
$$G=B+P-T$$
$$G=B+(P-T)$$
$$G = D \quad B = A \quad \therefore \quad D = A+(P-T)$$

Now it will be remembered that angles are measured in mils and the value of P and T may be determined, knowing

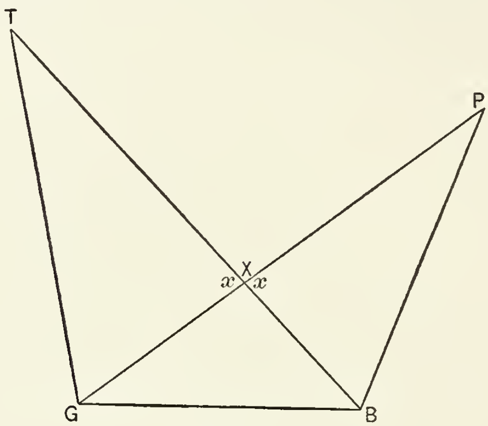


Fig. 2.

the range, the distance to the aiming point, and the distance from the guns to the observing station or GB in the figure.

Thus if R is 3,000 yds. a mil subtends 3 yds., and if GB is 60 yds., it must be subtended by an angle of 20 mils, hence: $T = 20$.

If BP is 2,000 yds. a mil subtends 2 yds., and if GB is 60 yds. it must be subtended by an angle of 30 mils, hence: $P = 30$.

Now if the azimuth or *a* is 1,600 mils as measured by the telescope, we have:

$$D = 1600+30-20 = 1610.$$

This is the principle upon which deflection is determined by the parallax method prescribed in the Drill Regulations.

The easiest way to grasp the parallax method is first to

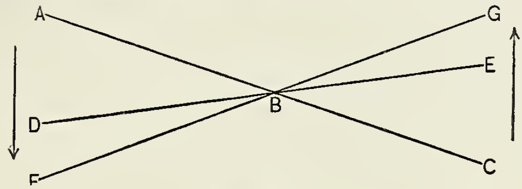


Fig. 4.

understand the meaning of the work parallax. This word is derived from the Greek word *parallaxis*, from *para*, beyond, and *allassein*, to change.

The parallax then is the apparent change of position of an object when viewed from different places.

An observer at A, Figure 4, sees an object at B in a line with C, but when he moves to the positions D and F it appears in line with E and G respectively. This apparent alteration of position, as if the object were retreating as the observer advances, is called parallax. Parallax is measured by the angle at the object. Thus the parallax of B, with respect to positions A and D, is the angle ABD, which, of course, is equal to the vertical angle EBC.

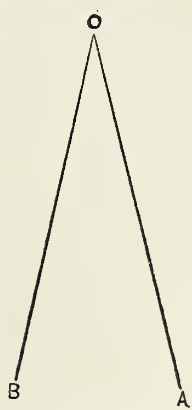


Fig. 5.

Parallax may again be illustrated by Figure 5.

Suppose A and B are your eyes and O an object. If you close the right eye your line of sight is BO, and if you close the left eye your line of sight is AO.

The angle BOA is the optical or binocular parallax. It is readily seen that as the object recedes the angle decreases.

Optical parallax can be easily tested in the following manner.

Place a pencil on the floor at the left edge of a door frame so that it can just be seen with the right eye as you look through the door opening. Close the right eye and the pencil will disappear. This is just what happens when the battery commander leaves his station for the guns. The target disappears. From his station it is necessary for him to calculate firing data with his open eye for the blind eye of the battery.

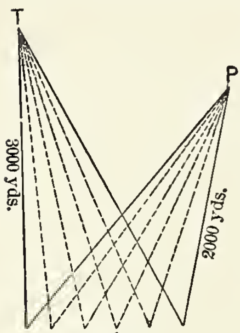


Fig. 6.

For the sake of convenience a handy rule has been worked out, which, based upon the foregoing principle, shortens the calculation of deflection. The parallaxes of the angles P and T have been calculated for every range with a base of 20 yds. or 1 platoon front, thus:

If range is 3,000 yds. each mil has a lineal value of 3 yds. and the angle T (Figure 6) must be $6\frac{2}{3}$ mils to subtend the base of 20 yds. The nearest whole number is taken, so that in this case the parallax of T is 7. In other words, to determine the parallax of any angle divide 20 yds. by 1/1,000 of the range; thus:

$$T = 20/3 = 6\tfrac{2}{3} = 7$$
$$P = 20/2 = 10$$

But in Figure 6 the base is 100 yds. and angles at P and T are five times larger than they would be for a base of 20 yds. Therefore, they are: $5 \times 7 = 35$ and $5 \times 10 = 50$.

We found that:

$$D = a + P - T$$
$$D = a + (P - T)$$

If we take the value of (P—T) for a 20-yd. base (10—7), and multiply the bracket by the number of times 20 goes into the base, or $\frac{100}{20} = 5$, we have the actual value of (P—T); a is measured with the instrument; therefore:

$$D = a + 5\ (10-7)$$

The rule is generally stated:

$$D = a + n\ (P-T)$$

n is the number of platoon fronts in the base.

If the observing station is on the right of the guns *n* is always positive or plus (+); if on the left n is always negative

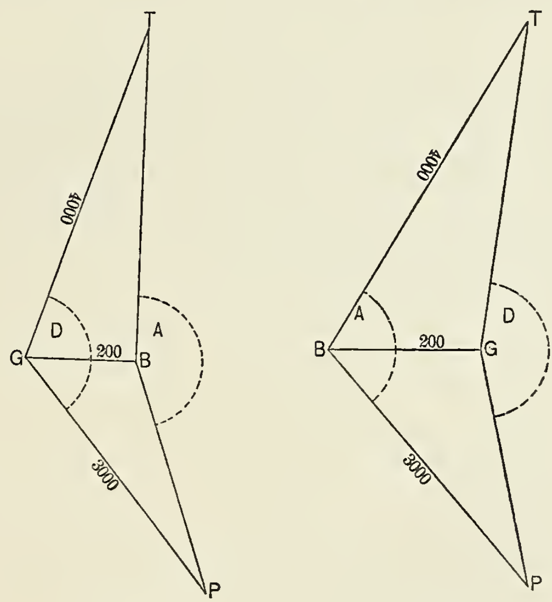


FIG. 7. FIG. 8.

or minus (—). And so if the aiming point is in front of the prolongation of the line of guns P is positive (+); and if in

rear it is negative (—). In all these calculations it is assumed that the base is so small compared to the range and the distance to the aiming point that GT is equal to BT, and that BP is equal to GT. Of course, the base in the figure is largely exaggerated.

Now let us calculate the deflection when the aiming point is in the rear and the observing station is on the right (Figure 7).

$$D = a + n\ (P—T)$$

If the base is 200 yds. $n = \frac{100}{20} = 5$. Since the station is on the right n is positive.

$T = \frac{20}{4} = 5$. $P = \frac{20}{3} = 7$ (Negative because in rear.)

$$(P-T) = (-7-5) = (-12)$$
$$\text{or } n\ (P-T) = 5(-12) = -60$$

A is measured with the instrument and found to be 2,600 mils.

$$\therefore D = 2{,}600 + 5(-12) = 2{,}600 - 60 = 2{,}540.$$

If AP is in rear and the observing station is on the left, the result is different. (Figure 8.)

$$D = a + n\ (P—T)$$

$n = 200/20 = -10$. (Since station is on the left it is negative.)

$$T = 20/4 = 5 \qquad P = 20/3 = -7$$
$$(P—T) = (—7—5) = —12$$
$$n\ (P—T) = —10(—12)$$

A is measured and found to be 2,600 mils.

$$D = 2{,}600 + (-10(-12))$$
$$D = 2{,}600 - 10(-12)$$
$$D = 2{,}600 + 120$$
$$D = 2{,}720$$

Now it will be observed that when the observing station

was on the right D was less than A or the deflection was less than the azimuth; and when the observing station was on the left D was greater than A. These results are graphically illustrated by the figures. The contained angle must naturally be the larger.

The rule of the Drill Regulations should now be readily understood. It is:

Rule V. The deflection of the right piece is equal to the angle from the aiming point to the target (A), as measured at the observing station, increased algebraically by as many times the convergence difference (P—T) as there are platoon fronts (n) in the interval between observation station and right piece; or

$$D=A+n\ (P—T).$$

So far, however, we have only calculated the deflection of the right piece. If the guns are 20 yds. apart and each one is laid with the same deflection, it is obvious that there would

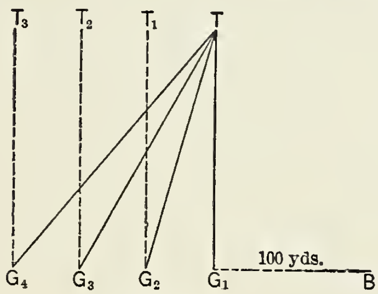


FIG. 9.

be four parallel lines of fire, the right one only passing through the target. (Figure 9.)

It is necessary, therefore, to converge G_2, G_3, and G_4 upon T.

$$BG_1=n=5.$$

If the pieces are 20 yds. apart:

$$BG_2 = n+1 = 6$$
$$BG_3 = n+2 = 7$$
$$BG_4 = n+3 = 8$$

Or deflection for the pieces is

$$DG_1 = A+5(P-T)$$
$$DG_2 = A+6(P-T)$$
$$DG_3 = A+7(P-T)$$
$$DG_4 = A+8(P-T)$$

Now the differences between the deflection of G_1 and the other pieces or the deflection differences (DD) are:

$$(G_2) \quad A+5(P—T)—A+6(P—T) = 1(P—T)$$
$$(G_3) \quad A+5(P—T)—A+7(P—T) = 2(P—T)$$
$$(G_4) \quad A+5(P—T)—A+8(P—T) = 3(P—T)$$

Hence; if these are the deflection differences between the 2d, 3d and 4th piece and the right or 1st piece, the extent

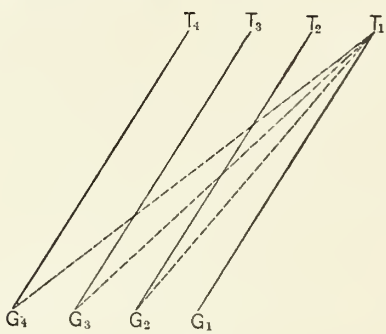


FIG. 10.

any piece must be converged is equal to the deflection difference of the 1st piece or (P—T) multiplied by the number of platoon fronts from the right piece.

If the pieces were converged upon T_1 (Figure 10) only one point of a wide front would be subjected to fire. If the pieces were not converged still only a small portion of the front would

be affected by the parallel fire of the guns. The natural thing to do, therefore, is to divide the entire front of the target and give each piece a fourth to fire upon. This is distributing the fire. In order to distribute the fire we must first converge upon T_1. The convergence differences are:

$$\text{CD of } G_2 = (P-T)$$
$$\text{CD of } G_3 = 2(P-T)$$
$$\text{CD of } G_4 = 3(P-T)$$

Now if the range is 2,000 yds. each mil subtends 2 yds. If the front (F) is 200 yds. wide $\frac{1}{4}$ F=50 yds. 50 yds. would be subtended by 25 mils at the gun or 25 mils would have to be added to the deflection of G_2 to throw its fire $\frac{1}{4}$ of the front to the left of T_1.

Now then, to the convergence difference of each piece we must add $\frac{1}{4}$ of F multiplied by the number of platoons from the right gun. Therefore,

$$\text{DD for } G_2 = (P-T)+\tfrac{1}{4}F;$$
$$\text{DD for } G_3 = 2(P-T)+2(\tfrac{1}{4}F) = 2((P-T)+\tfrac{1}{4}F)$$
$$\text{DD for } G_4 = 3(P-T)+3(\tfrac{1}{4}F) = 3((P-T)+\tfrac{1}{4}F)$$

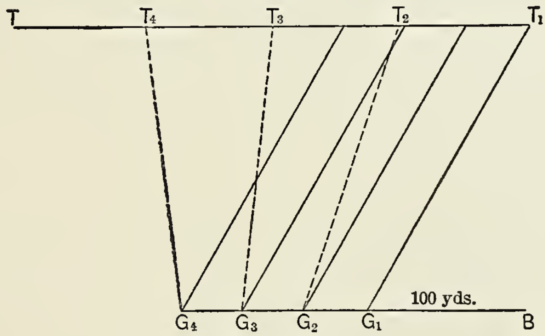


FIG. 11.

It will be seen that adding (P—T) for convergence and (P—T)+$\frac{1}{4}$F for distribution to the deflection of any one piece gives the deflection of the next piece.

The convergence difference for each piece then is as follows:

$$(G_2) \qquad CD = (P-T) \text{ or } DD$$
$$(G_3) \qquad CD = 2(P-T) \text{ or } 2DD$$
$$(G_4) \qquad CD = 3(P-T) \text{ or } 3DD$$

Now let us consider a target with a wide front. (Figure 11.) If it be desired to converge, and $(P-T) = -10$:

$$D \text{ for } G_1 = 3{,}200;$$
$$D \text{ for } G_2 = 3{,}200 + (-10) = 3{,}190$$
$$D \text{ for } G_3 = 3{,}190 + (-10) = 3{,}180$$
$$D \text{ for } G_4 = 3{,}180 + (-10) = 3{,}170$$

The same results are obtained by the other method, viz.:

$$D \text{ for } G_1 = 3{,}200$$
$$D \text{ for } G_2 = 3{,}200 + (-10) = 3{,}190$$
$$D \text{ for } G_3 = 3{,}200 + 2(-10) = 3{,}180$$
$$D \text{ for } G_4 = 3{,}200 + 3(-10) = 3{,}170$$

And for distribution the first method is:

$$D \text{ for } G_1 = 3{,}200$$
$$D \text{ for } G_2 = 3{,}200 + (-10) + 25 = 3{,}215$$
$$D \text{ for } G_3 = 3{,}215 + (-10) + 25 = 3{,}230$$
$$D \text{ for } G_4 = 3{,}230 + (-10) + 25 = 3{,}245$$

And by the other method the same result is obtained.

$$D \text{ for } G_1 = 3{,}200$$
$$D \text{ for } G_2 = 3{,}200 + 1((P-T) + \tfrac{1}{4}F) = 3{,}200 + (-10) + 25 = 3215$$
$$D \text{ for } G_3 = 3{,}200 + 2((P-T) + \tfrac{1}{4}F) = 3{,}200 + 2((-10) + 25) = 3230$$
$$D \text{ for } G_4 = 3{,}200 + 3((P-T) + \tfrac{1}{4}F) = 3{,}200 + 3((-10) + 25) = 3245$$

If all four of the pieces are converged upon the target and it be desired to resume parallel fire, the deflection difference is equal to the parallax of the target. (Figure 10.)

The desired direction for G_2 is G_2T which is parallel to G_1T_1 and angle T_1 or the necessary deflection for the line of

fire for G_2 is equal to the angle T or the parallax of the target. Therefore, for parallel fire—

$$DD = P.$$

Referring to Figure 11, it will be seen that with shrapnel fire a part of the effect of the right gun would be lost if G_1 were directed straight at T_1 and also that the extreme left of the front would be uncovered. This is provided for by directing the right gun about 10 yds. within the right edge. One gun can only cover effectively about 20 yds. of front so that if the front is over 80 yds. there are spaces unswept by fire. If these spaces are large they may be covered by using sweeping fire.

The Drill Regulations, paragraph 437, tell us that, when the observing station is in advance or in rear of the line of guns, the formula $D = A + n\ (P—T)$ is only approximately correct. Major McNair solves the problem by a method he calls the fictitious gun method, which is as follows (Figure 12):

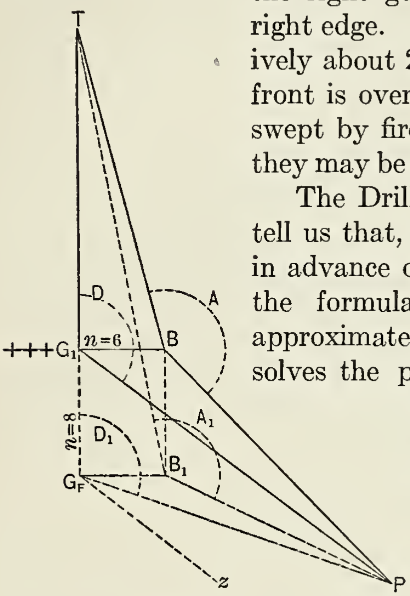


FIG. 12.

The formula $D = A + n\ (P—T)$ will give the angle D for the right gun, G_1, and an observing station at B. So would the formula give the angle D_1, for a gun at G_F and an observing station at B_1. It is manifest that D_1 and D are not equal.

Draw a line, G_FZ, through G_F and parallel to the line G_1P. It is seen that angle ZG_FT is equal to angle PG_1T or D.

The angle ZG_FT is made up of two angles, namely, $PG_FT = D_1$ and PG_FZ. Therefore D is greater than D_1 by the angle PG_FZ.

Since G_FZ and G_1P are parallel, angle PG_FZ is equal to angle G_1PG_F. But angle G_1PG_F is the parallax of the point P with respect to the line G_FG_1.

Suppose the angle A_1 to be 1,700 mils; the range to target 3,300 yds.; and the distance to P from B, 1,000 yds. Then P $=0$ and $T=6$ and $n=6$. Applying the formula:

$$D_1 = 1{,}700 + 6(0-6) = 1{,}664.$$

But we have seen that this angle is too small by the parallax of P times the number of platoon fronts in G_FG_1 or since the parallax of $P=20$ and $G_FG_1=8$ platoon fronts, we must add $8\times 20=160$ mils to the angle given by the formula in order to be nearly correct.

The more distant P the smaller its parallax, and if very distant $8\times P$ would be so small as to be negligible.

Again, if the aiming point had been nearly in rear of the guns, its parallax with respect to the line G_FG_1 would have been greatly reduced on account of its obliquity to that line and $8\times P$ would have been negligible.

Therefore, unless aiming points are quite close and have considerable obliquity, the correction for the fictitious gun need not be made as the parallax method is only approximate at its best.

When Aiming Points Are Not Available.—So far, in dealing with the subject of deflection, we have assumed a suitable aiming point available. Under such circumstances the calculation of deflection in the field is comparatively simple when once the underlying principles are well understood. The practical difficulties of indirect fire, however, lie in the absence of aiming points visible from all the guns and the observing station. One who has had the slightest experience in the field must be struck by the difficulties encountered in securing such a point, especially in a low or in a close country. In actual service many of the difficulties encountered at drill may be obviated by the free use of the axe.

If an aiming point visible from all the guns and from the observing station can not be found, then some expedient must be devised for directing the guns upon their targets. The following are given as examples of such expedients:

Example 1.—To Direct a Piece Upon the Target.—Suppose no aiming point is visible, that the guns are in position behind

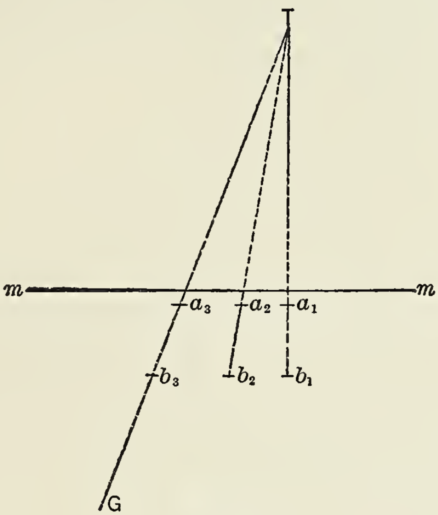


FIG. 13.

a mask, and it be desired to direct one of the pieces upon the target.

Solution.—In Figure 13, let T be the target, G the gun to be directed, and *mm* the ridge of the intervening mask.

Let a man take a position as at a_1 from which he can see the target, and another take the position b_1 from which he can line a_1 with the target. The gunner directs them to move to successive positions as a_2 and b_2, a_3 and b_3, until the two men give the proper direction. The rear man must always keep the front one in line with the target and the gunner causes them both to move until b_3 covers a_3.

Example 2.—Use of a Directing Piece.—The guns are in a depression and all view of the surrounding country is cut off. No natural aiming points are visible.

Solution.—First, at least one gun must be directed upon the target. If the battery commander can look over the line of metal, from a tower, or a tree, he can direct a piece upon its appropriate part of the target with fair accuracy. But observing towers and natural points of vantage are not commonly to be found in the field, and more often some such

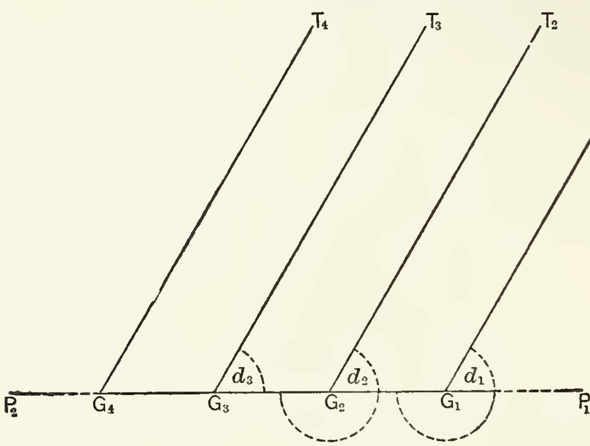


FIG. 14.

method of directing a gun as the one described in Example 1 must be relied upon.

Let us suppose, in Figure 14, that the third piece has been directed upon the target and that parallelism of the lines of fire of all the guns has been secured.

Now suppose G_1 is the aiming point employed by G_3. The deflection for G_3 is the angle d_3. But if the sight of G_3 is employed by G_2 and G_1 as an aiming point, the deflection of G_2 and G_1 for parallel fire is the angle $d_2+3{,}200$, and $d_1+3{,}200$ respectively.

But d_2 and d_1 both equal d_3.

Therefore the formula for the deflection for G_2 is

$$D_2 = D_3 + 3{,}200.$$

And the formula for the deflection of G_1 is

$$D_1 = D_3 + 3{,}200.$$

Therefore, if a directed piece be used as an aiming point the deflection for parallel fire for all the pieces to the right thereof is the deflection of the directed piece+3,200.

Now consider G_4, in Figure 15.

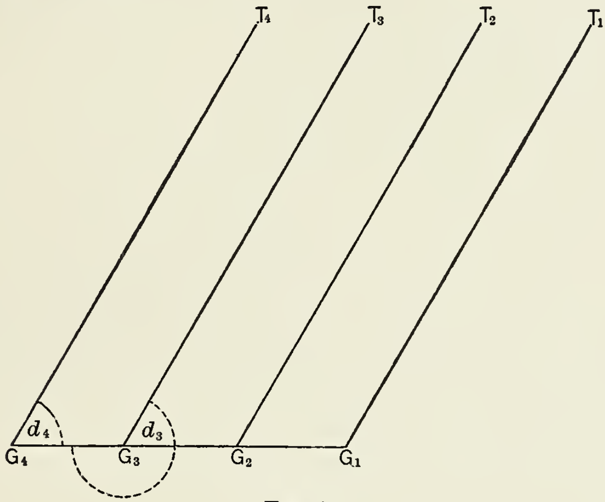


FIG. 15.

Suppose G_3 be laid on T_3 with the sight of G_4 as an aiming point. The deflection of G_3 is the exterior angle at G_3, or the angle $d_3+3{,}200$. But the deflection of G_4 for parallel fire if G_3 be used as an aiming point is the angle d_4.

$$D_4 = d_4 = d_3, \text{ or}$$
$$D_4 = d_3$$
$$D_3 = d_3 + 3{,}200$$
$$D_3 - 3{,}200 = d_3 + 3{,}200 - 3{,}200$$
$$D_3 - 3{,}200 = d_3$$
$$d_3 = D_4$$
$$\therefore D_3 - 3{,}200 = D_4$$

Therefore, if the sight of a directed piece be employed as an aiming point, for parallel fire the deflection of all pieces to the left thereof is the deflection of the directed piece—3,200.

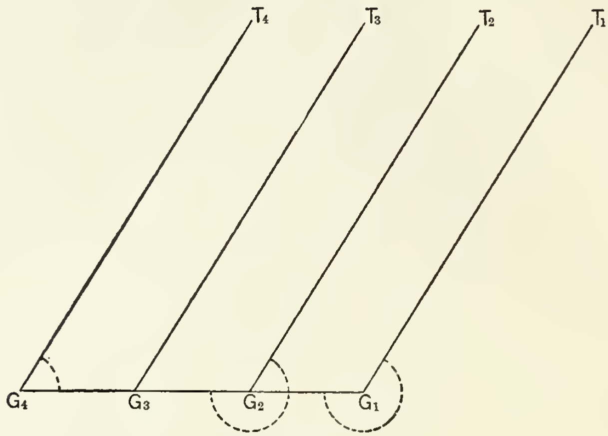


FIG. 16.

The formulæ having been deduced, now let us apply them in Figure 16.

Suppose G_3 directed upon the target. To compute deflection for the other pieces proceed as follows:

Cause the gunner of the third piece to turn his panoramic sight upon the panoramic sights of each of the other pieces in turn and to read off the respective angles.

For pieces to the right of the directed piece the angle is increased by 3,200, and for pieces to the left it is diminished by 3,200, the resultants being the deflections to be employed for the pieces respectively, the panoramic sight of the directed piece being the aiming point for all other pieces.

Obviously, it is immaterial which piece is directed upon the target to start with. Naturally the one which can be directed with the greatest facility should be employed. If the first piece is directed, its deflection from the sights of the other pieces will be diminished by 3,200 for every other piece, and

if the fourth piece is directed its deflection from the sights of the other pieces will be increased by 3,200 for every other piece.

Now suppose (Figure 17), that parallelism of fire has been secured by the foregoing method. The use of the sight of the directed piece, as an aiming point, can now be abandoned and

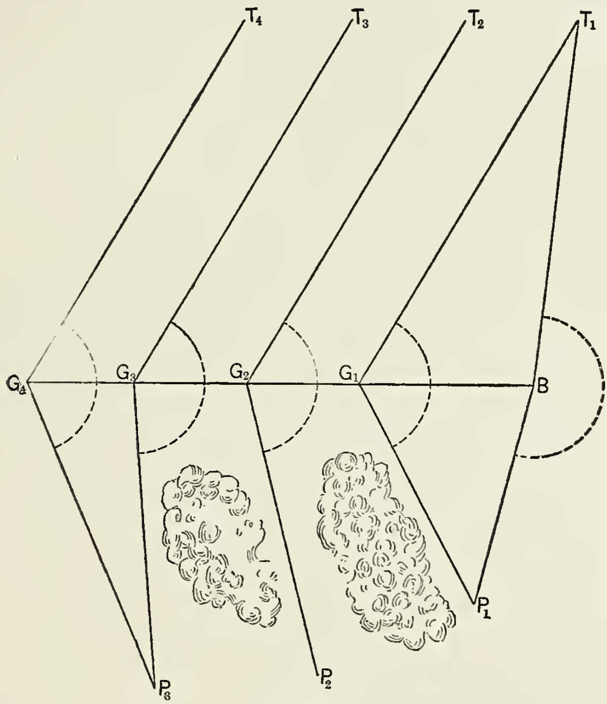


FIG. 17.

any other suitable point can be selected by the gunners. A common point for the four pieces may be designated or each gunner may use a different point. In the figure the gunner at G_1 cannot see P_2 or P_3, neither can the gunner at G_2 see P_1 or P_3. The gunners of the third and fourth pieces cannot see P_1 and P_2, but they can both see P_3 and therefore use it in

common. All the gunners set their sights on their new aiming point, pieces having already been directed.

Each gunner should chalk up the reading of his sight, when first directed upon the new aiming point, on his gun shield. It is apparent in Figure 17 that the deflection reading of each piece will be different although the line of fire of the four guns is parallel. If the battery commander attempted to shift the sheaf by designating a common deflection for the guns, parallelism of fire would be lost, since the aiming points are not common. Therefore, the sheaf must be shifted to the right and to the left, by subtracting and adding a common angle to the individual deflections of the pieces. It is obvious that, if the lines of fire are parallel and each gunner add or subtract 100 mils to or from the deflections of his piece, parallelism of fire will still obtain.

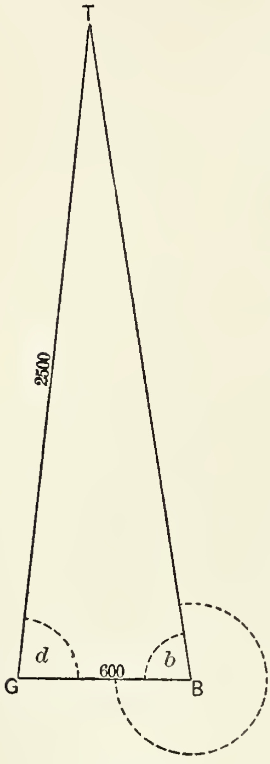


FIG. 18.

Example 3.—Combination of Methods.—An aiming point is visible from the observing station and from a single or several guns, but not from all the guns. (Figure 17.)

Solution.—The aiming point should be employed by as many guns as possible, the deflection for these guns being computed in the usual way. The other gun or guns may then use the sight of a directed piece for an aiming point as explained in Example 2, and, after being laid, employ a secondary aiming point. This solution is merely a combination of the regular method and an expedient. The battery commander is constrained, however, to shift the sheaf by adding and subtracting instead of by designating a common deflection.

In Figure 17, P_1 could be employed to lay the right piece, the deflection for which having been calculated at the station in the regular way, and the piece having been laid, the gunner could then assist the other gunners to direct their pieces by reading the deflection for the right gun from the panoramic sights of the other pieces. G_2, G_3, G_4, could then be laid by the use of the panoramic sight of G_1, as an aiming point, as in Example 2, the direction of the pieces thereafter being referred to the secondary aiming points, P_1, P_2, P_3.

Example 4.—B. C. Telescope as Aiming Point.—Suitable aiming points can be seen from the guns, but none of them are visible from the observing station, which, on account of the lay of the ground, must be located on the flank and at a considerable distance from the guns. The guns and the station are clearly visible, however, one from the other.

Solution.—In Figure 18, let T be the target, G the right piece, and B the observing station. Let GB be 600 yds., BT 2,500 yards and GT 2,500 yards.

A mil at T intercepts 2.5 yds. at the guns.

Therefore

$$T = 600 \div 2.5 = 240 \text{ mils.}$$

Lay the B. C. telescope on G and measure the exterior angle B. Suppose it be 5,000 mils. Then the interior angle b is known for

$$\begin{aligned} b &= 6{,}400 \text{ mils } - B \\ b &= 6{,}400 \text{ mils } - 5{,}000 \text{ mils.} \\ &= 1{,}400 \text{ mils.} \end{aligned}$$

Now then $T = 240$ mils and b 1,400 mils. Since the sum of the three angles of a triangle equal 3,200 mils

$$\begin{aligned} d + b + T &= 3{,}200 \\ d &= 3{,}200 - (b + T) \\ d &= 3{,}200 - (1{,}400 + 240) \\ &= 3{,}200 - 1{,}640 \\ &= 1{,}560 \end{aligned}$$

It is apparent then that the angle *d*, that is the angle between the observing station and the target, can always be computed at the observing station. This being so, all that is necessary to direct the right gun upon the target is to lay the piece with a deflection equal to this angle, using the B. C. telescope as an aiming point.

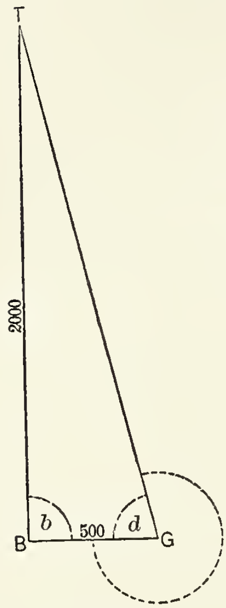


FIG. 19.

The Drill Regulations, 1908, paragraph 446, Example 2, prescribe a ready rule, which simplifies the calculation. By setting the telescope at 3,200, directing it upon G and then upon T, the angle *b* is at once given, rendering unnecessary the calculation of the exterior angle B and its subtraction from 6,400 in order to determine *b*.

Let us follow the rule in the Drill Regulations.

If the telescope be set at 3,200 and sighted at G, and then at T, a reading of 3,200 less the angle *b* will be obtained, since the telescope is turned to the right. The reading will be $3{,}200-1{,}400$ or 1,800. $T=500\div 2.5=240$. Subtract T, as the station is on the right.

$$1800—240=1{,}560$$

This is the same result before obtained.

Now let us compute the deflection when the observing station is on the left (Figure 19).

$$T=\frac{500}{2}=250.$$

Read the angle *b* with the telescope. Suppose it be 1,400 mils. Then $d+b+T=3{,}200$.

$$\begin{aligned} d&=3{,}200-b-T=3{,}200-(b+T)\\ &=3{,}200-(1{,}400+250)\\ &=1{,}550. \end{aligned}$$

This is the value of *d*, and not of the exterior angle G which the sights lay off. But the angle G = 6,400—*d*

$$= 6{,}400 - 1{,}550$$
$$= 4{,}850$$

The battery commander would then command:

1. Aiming point the B. C. telescope.
2. By battery from the right.
3. Deflection 4,850.
4. Etc., etc.

Following the rule in the Drill Regulations we secure a similar result, as follows:

If the telescope be set at 3,200 upon G and then sighted at T a reading of $3{,}200+b$ or $3{,}200+1{,}400$ or 4,600 would be obtained.

$$\text{BG is 500 yds. } T = \frac{500}{2} = 250.$$

The station is on the left and the value of T must be added; thus:

$$4{,}600 + 250 = 4{,}850.$$

The pieces having been directed upon the target by the use of the B. C. telescope as an aiming point, the direction of the pieces may be from now on referred to the secondary aiming points visible from the guns. Should the battery commander be forced to move his station for any reason, a marker should be substituted for the telescope, unless the secondary aiming points are to be used; otherwise the true direction would be lost since there would be no common point of reference for the panoramic sights of the guns and the combined effect of uneven ground, creeping, and jump would soon destroy the effectiveness of the sheaf.

The Plotter.—The plotter is a mechanical device which permits us to transform the range and direction of the target

as obtained at the observing station so as to make the data available for use at the guns. By the employment of this instrument a graphic solution is obtained, rendering unnecessary the use of the formulæ.

At the observing station the distances to target, aiming point, and right piece are measured by the range finder or the distances may be estimated. The angles from aiming point to target and from aiming point to right piece are measured by the B. C. telescope. The data as found at the observing station is then set off on the instrument, the protractor is moved along its slide a distance corresponding to the distance between observing station and right piece, and the range and direction of the target from right piece are read off.

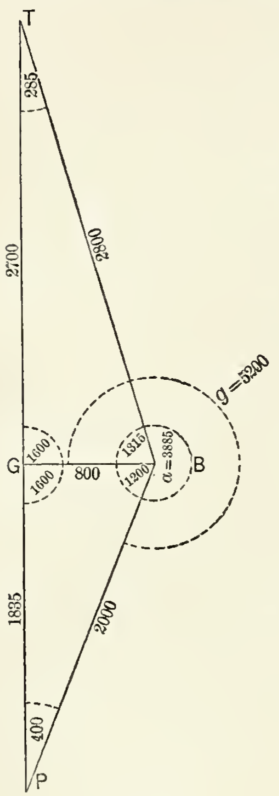


Fig. 20.

The plotter is an exceedingly valuable instrument and will, at times, be found all but indispensable. One difficulty arises in its use, however: frequently in a close country an aiming point visible from the guns cannot be found sufficiently distant from the observing station to permit of the accurate calculation of deflection with the plotter. This is the case when an aiming point on a flank of the guns must be employed which is not 1,100 yards distant from the station. In the construction of the plotter, an aiming point nearer than 1,100 yards to the station was not contemplated and the instrument cannot, therefore, be properly adjusted under such circumstances.

Every artillery officer should be as familiar with the use

of the plotter as with that of the B. C. telescope. The principle of the instrument is as follows:—

Explanation of the Plotter.—Let us consider Figure 20, in which the aiming point, the right gun, and the target make with each other a straight angle or an angle of 3,200 mils; the observing station being 800 yards distant on the right flank; the distances from the station to the target and to the aiming point being 2,800 and 2,000 yards respectively.

The sum of the three angles of the lower triangle, that is of the triangle GPB, is equal to 3,200 mils. G = 1,600 mils. If BP is 2,000 yds. the parallax of P is 400.

$$\begin{aligned} B+P+G &= 3{,}200 \\ B &= 3{,}200-(P+G) \\ &= 3{,}200-(400+1{,}600) \\ &= 1{,}200 \end{aligned}$$

In the upper triangle, or the triangle BTG, the sum of the three angles is also equal to 3,200 mils. G = 1,600. If BT is 2,800 yds. the parallax of T is 285.

$$\begin{aligned} B+T+G &= 3{,}200 \\ B &= 3{,}200-(T+G) \\ &= 3{,}200-(285+1{,}600) \\ &= 1{,}315 \end{aligned}$$

The azimuth of T with respect to P is the exterior angle at B, which is equal to 6,400 mils less the sum of the two interior angles.

$$\begin{aligned} A &= 6{,}400-(1{,}315+1{,}200) \\ &= 6{,}400-2{,}515 \\ &= 3{,}885 \end{aligned}$$

The azimuth of the right gun G with respect to P is the angle g, or

$$\begin{aligned} g &= 3{,}885+1{,}315 \\ &= 5{,}200 \end{aligned}$$

In the right-angle triangle BPG the square of the hypote-

nuse is equal to the sum of the squares of the other two sides, or

$$BP^2 = GP^2 + GB^2$$
$$GP^2 = BP^2 - GB^2$$
$$GP^2 = (2{,}000)^2 - (800)^2$$
$$= 4{,}000{,}000 - 640{,}000 = 3{,}360{,}000;$$
$$GP = \sqrt{3{,}360{,}000} = 1{,}835 \text{ approximately.}$$

The distance from right gun to aiming point is therefore approximately 1,835 yards.

In the right-angle triangle BTG,

$$GT^2 = BT^2 - GB^2$$
$$= (2{,}800)^2 - (800)^2 = 7{,}200{,}000;$$
$$GT = \sqrt{7{,}200{,}000} = 2{,}700 \text{ approximately.}$$

The distance from right gun to target or the range is, therefore, approximately 2,700 yards.

Of course, the foregoing mathematical calculations for the azimuths and the distances are not necessary in the field. The angles are obtained in practice by merely sighting the B. C. telescope first at the aiming point and then at the object, the azimuth of which is desired, the distances being estimated, or determined with the range finder. The foregoing solution, however, is exactly the one given by the plotter. The plotter is adjusted as follows:

1. Unclamp the arms of the plotter and the arm slides.
2. Clamp the protractor on the gun arm at zero.
3. Read the azimuth of the right gun with respect to the aiming point with the B. C. telescope.
4. Revolve the aiming point arm until the zero of the inner circular scale is opposite the figure on the outer circular scale corresponding to the azimuth of the gun; *g* in the figure being 5,200 mil. Clamp the arm.
5. Set the zero on the slide of the aiming-point arm at the point of its scale corresponding to the distance of the aiming

point from the observing station; 2,000 yards in the figure. Clamp the slide.

6. Read the azimuth of the target with the B. C. telescope.

7. Revolve the target arm of the plotter until the zero of its vernier scale is opposite the figure on the outer circular scale corresponding to the azimuth of the target; *a* being 3,885 in the figure. Clamp the arm.

8. Set the zero on the slide of the target arm at the point of its scale corresponding to the distance of the target from the observing station; 2,800 yards in the figure. Clamp the slide.

9. Unclamp the protractor.

10. Turn the screw of the protractor until the number on the scale of the gun arm, corresponding to the distance of the right gun from the observing station, is brought opposite the zero.

11. Clamp the protractor.

12. The deflection of the right gun is the reading opposite the zero of the vernier on the target arm. The plotter will give 3,200 mils, which checks with the geometrical solution in Figure 20.

13. The range from right piece to target is the reading of the slide scale on the target arm. The plotter will give about 2,700 yards.

14. The distance from right piece to aiming-point is the reading of the slide scale on the aiming-point arm. The plotter will give about 1,835 yards, which also checks with the figure.

If the foregoing steps are followed out, the relative directions of the three arms of the plotter will correspond to the relative directions of the aiming point, target, gun, and observing station in Figure 20. If in practice the gun arm be pointed from the observing station to the right gun, when adjusted, the other two arms should point in the actual direction of the aiming point and target respectively, the instrument itself giving a graphic solution by the relative position of its arms.

If there is the slightest difficulty, either in understanding the principle of the plotter, or its manipulation, each of the

foregoing steps should be gone over, time and again, with Figure 20 before the eyes. If this be done the trouble will soon be disposed of.

Measurement of Angles.—We have seen that the azimuth of the target, or the horizontal angle between the aiming point and the target, may be measured by the B. C. telescope and transformed so as to give the deflection of the right piece either by the parallax method (mathematically) or by the use of the plotter (graphically).

There are still other ways in which the azimuth of the target may be measured, namely, by use of the battery commander's ruler and by measurement with the hand. It is needless to say that the B. C. telescope is the most accurate means and should be used when possible under all the circumstances.

The B. C. Ruler.—The battery commander's ruler is a slide ruler 6.7 inches long by 1 inch wide, with a cord about 24 inches long passing through a hole in the center. (See Handbook of the 3-Inch Field Artillery Material, 1908, p. 114.) The instrument affords a scale for quickly measuring azimuths, a slide rule for determining the height of the trajectory in mils at any point of the range, and a table of parallaxes computed for a base of 20 yards and varying ranges and angles of obliquity of base to range. The front or slide face of the ruler has the azimuth and height of trajectory scales; the reverse face the parallax table. (See Figure 24.)

For measuring azimuths, the scale on either edge of the slide face of the ruler is used in connection with the cord. When one end of the cord is attached to the top button of the coat or held in any other convenient way, and the ruler held horizontal and perpendicular to the taut cord at a distance of 20 inches from the eye, the scale on the edge of the ruler measures in mils the visual angle subtended by the corresponding portion of the ruler. The cord supplied with the ruler is sufficiently long to permit a loop to be formed for slip-

ping over the button of the coat. The cord can be adjusted to the proper length by measuring, by means of the telescope or panoramic sight, the angle subtended by the distance between two convenient objects, and then adjusting the length of the cord so that the ruler will give the individual using it the same reading. The personal equation necessarily enters into the adjustment of the cord.

On one edge the scale reads from 0 to 300 mils and on the other edge from 6,100 through 6,300 to 0. The graduations are made for every 2 mils and figured for every 10 mils. In each case the scale reads in the same direction as the azimuth scale on the panoramic sight. The 0 is also marked with a letter "T" for "target," since in using the ruler that point is placed on the target.

This scale is used for quickly finding the azimuth between the target and the aiming point, measuring the front of a position, determining the correction in azimuth which should be made to bring on to the target projectiles striking to one side, and similar data. It will be especially useful when the battery commander's telescope is not available on account of lack of time or for other reasons.

To use the ruler in measuring azimuths, the 0 (or "T") of the scale should be held on the line joining the eye and the target or other origin of measurements. If the point the azimuth of which is required lies to the right of this origin, the ruler is held in the right hand and the scale on its upper edge is used. If, however, the point the azimuth of which is to be determined lies to the left of the origin, the ruler is held in the left hand and the scale on the lower edge is used, the ruler being reversed to bring the scale on top. The reading of the scale at the line joining the eye and the point then gives the azimuth of this point with reference to the origin. In practice, the thumb and forefinger of the hand holding the ruler are used to mark the intersection of this line and the scale. (For use of slide scale see subsequent chapter on The Mask.)

Measurement by Hand.—If the hand be held in a vertical position at full arm-length from the body, it will obliterate a portion of the horizon or of the landscape, the amount obliterated or covered depending upon the length of the arm and the width of the hand at the point considered. The personal equation enters largely into measurement by this means, for not only the foregoing factors but the manner in which the observer stands affects the measurement. Each observer, then, must establish and observe a uniform method in order to obtain even approximately uniform and accurate results. The best method is perhaps that of standing with the right arm in prolongation of the line of the shoulders and turning on the heels as the arm is moved without changing the position of the heels. In this case the position of the heels is the center of a circle, the line from the wrist to the center of the body is the radius, and the arc of the circumference intercepted by the width of the hand is constant no matter in what direction the observer faces. The same horizontal line through the hand should, of course, always be considered.

Having adopted a uniform method, it is now necessary to determine the amount of the circumference or the arc which the hand intercepts. This may be done as follows: Standing in the position adopted, let the right edge (if the right arm is used) of the hand rest upon a prominent point well removed. Note carefully the exact point which clears the left side of the hand. Measure the angle between the two points with the B. C. telescope. Repeat the measurement a number of times, using different objects in each case. The sum of the angles measured divided by the number of these angles will give the mean or average arc intercepted and the corresponding angle subtended.

Having determined the mean value in mils of the width of the hand held vertically, palm outward, and arm fully extended, an angle or an arc may now be measured by moving the hand over the arc to be measured and multiplying the number of

successive movements necessary to cover the whole by the fixed value in mils of the hand.

With practice, measurements sufficiently accurate in the ordinary case may be obtained in this way.

Obliquity.—The parallax of a point the direction of which is normal to the front of the battery, usually true of the target, is easily obtained, as we have seen, by dividing 20 by the number of thousands of yards in the range of the point; thus the parallax of such a point 4,000 yards distant is 20 divided by 4, or 5 mils.

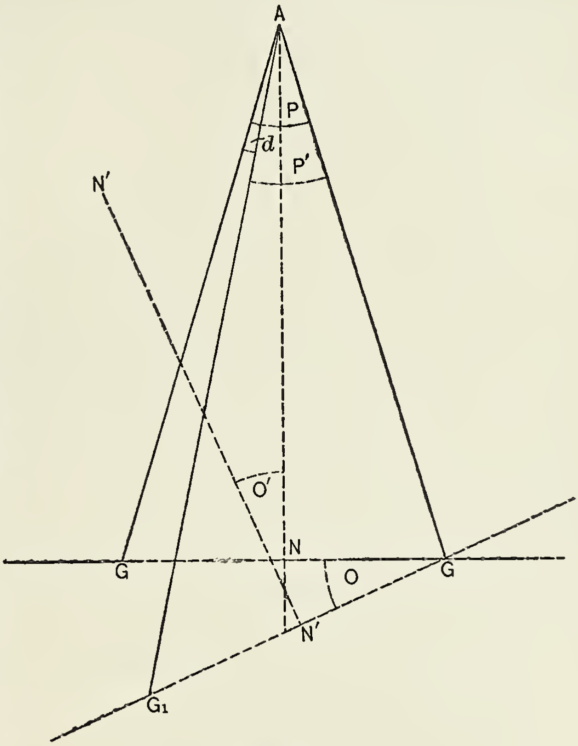


FIG. 21.

The term parallax is here used in a restricted sense and by the parallax of a point is meant the angle in mils subtended at the distance of the point by one platoon front, or 20 yds.

If the direction of the point is not normal to the front of the battery, its parallax is not that of a point equidistant and in a direction normal to the line of guns.

In Figure 21, let A be the aiming point in a direction NA,

normal to the line of guns GG. If GG be a platoon front the parallax of the aiming point is the angle P.

Now suppose the line of guns in the oblique position GG_1, GG_1 being equal to GG. Necessarily the aiming point is in a direction N′A oblique to the line of guns. The parallax of the aiming point with respect to GG is the angle P, but with respect to GG_1 it is the angle P′. But $P' = P - d$, the angle d measuring the decrease in the parallax due to the obliquity of GG_1.

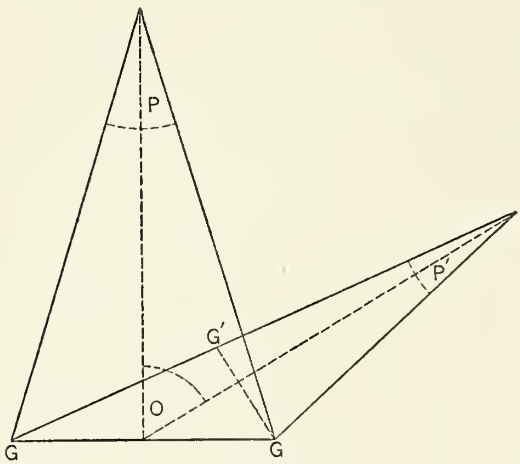


Fig. 22.

NA is the normal to GG. N′N′ is the normal to GG_1. The angle O′ included between the normals measures the obliquity of A with respect to GG_1. But angle O′ is equal to the angle O since the sides of the two angles are perpendicular, one to the other.

It is apparent that as the angle O, or the obliquity, increases the greater is the angle d, or the difference between the normal parallax and the actual parallax.

The necessity for a correction for obliquity is also obvious from Figure 22, in which P′ is in a direction oblique to the line of guns. The angle P′ is apparently less than the normal angle P, the angle O being the angle of obliquity.

From P a platoon front appears to be GG, but from P′ the platoon front is intercepted by the visual angle P′ which is the normal parallax of GG′ and not of GG. It should be here noted that the amount of correction for obliquity increases

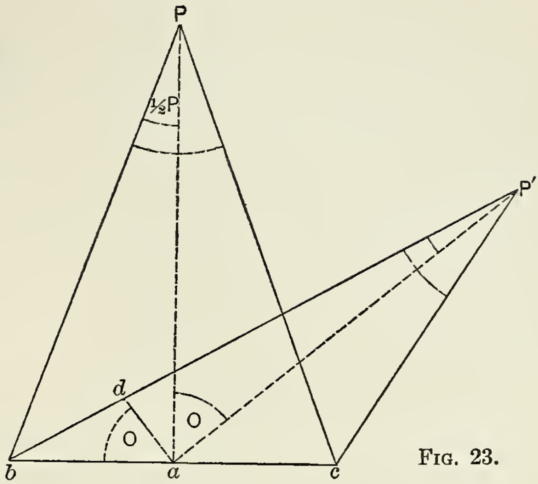


FIG. 23.

with the angle of obliquity, for the larger the latter the smaller the arc intercepted by the visual angle, or the smaller the actual parallax.

The value of P′, or the actual parallax, may be determined by trigonometric solution as follows:[1]

In Figure 23 let P be the normal parallax and P′ the actual parallax.

In the right triangle P*ba:*

$$\text{Tangent } \tfrac{1}{2}\, p = \frac{ab}{ap}$$

$$ap = \frac{ab}{\tan \tfrac{1}{2}\, \text{P}}$$

In the right triangle *p′ad,*

$$\text{Tangent } \tfrac{1}{2}\, p' = \frac{ad}{ap'},$$

$$ap' = \frac{ad}{\tan \tfrac{1}{2}\, p'}$$

[1] In trigonometry the sine of an angle is the ratio of the hypotenuse to the opposite side. Thus in Figure 23, sine of O (*dab*) is $\frac{ab}{db}$. The cosine of an angle is its complementary sine, or the sine of its complements; thus the cosine of O is the sine of *dab.* The cosine of an angle is the ratio of the adjacent side to the hypotenuse or the cosine of O is $\frac{ad}{ab}$. The tangent of an angle is the ratio of the opposite to the adjacent side, or tangent of ½ P is $\frac{ab}{ap}$.

In practice the distance ad is so small in comparison with dP' and aP' that the angle $P'da$ may be considered for all practical purposes as a right angle. Hence the angle abd is taken as a right angle.

This being so, the angles

$$P'aP = 90° - Pad$$
$$Pad = 90° - dab$$
$$P'aP = dab$$
$$\text{But} \quad P'aP = O$$
$$dab = O.$$

$$\text{Cosine of } O = \frac{ad}{ab} \quad \therefore ad = ab \text{ cosine } O.$$

$$\frac{ab}{\text{tangent } \frac{1}{2} P} = \frac{ad}{\text{tangent } \frac{1}{2} P'} \quad \text{or} \quad \frac{ad}{\tan \frac{1}{2} P} = \frac{ab \text{ cosine } O}{\tan \frac{1}{2} P'}$$

$$\tan \tfrac{1}{2} P' = \tan \tfrac{1}{2} P \text{ cosine } O$$
$$\tfrac{1}{2} P' = \tfrac{1}{2} P \cos O$$
$$P' = P \cos O.$$

Correction for Obliquity.—Since, therefore, it has been shown that the actual parallax is equal to the normal parallax multiplied by the cosine of the angle of obliquity, it becomes necessary in practice to correct the normal parallax when the point is in a direction oblique to the line of guns.

In indirect firing, the aiming point is usually, and the target frequently, located in directions oblique to the front of the battery and in determining azimuth difference for adjacent guns in the battery the parallax of both the aiming point and the target are used. The foregoing remarks about the correction for the obliquity of the aiming point also apply to the parallax of the target. The parallaxes of points for various ranges and angles of obliquity have therefore been computed and are tabulated on the battery commander's ruler in a form for convenient reference. This tabulation is as in Figure 24.

The two upper lines of figures in the table give angles of

obliquity for each 100 mils in the two quadrants in front of the battery, while the two lower lines give similar angles for the two quadrants in rear. The figures opposite 1,000, 1,250, 1,500, and 1,750 are the parallaxes for these ranges at the different angles of obliquity given in the table. For higher ranges simple multiples of the tabular ranges are taken. Thus, for 3,500 yards take one-half of the parallax for 1,750 yards; for 5,000 yards take one-fifth of the parallax for 1,000 yards, or one-fourth of that for 1,250 yards, etc.

In using the table, interpolation is, as a rule, unnecessary. It is sufficiently accurate for all practical purposes to take the direction of the point to the nearest 100 mils and the range to

	FRONT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		0	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
PARALLAX, HDS. MILS.	YARDS 1000	20	20	20	19	18	18	17	15	14	13	11	9	8	6	4	2	0
	1250	16	16	16	15	15	14	13	12	11	10	9	8	6	4	3	2	0
	1500	13	13	13	13	12	12	11	10	9	8	7	6	5	4	3	1	0
	1750	11	11	11	11	11	10	9	9	8	7	6	5	4	3	2	1	0
	REAR	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
		32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

FIG. 24.

the nearest tabular one or to the nearest multiple. Thus, for a point whose range is 2,800 yards, and whose direction, as given by the B. C. telescope, is 3,360, enter the table with a range of 3,000 yards (2×1,500) and take out the parallax corresponding to 34 (3,400), which in this case is found to be one-half of 13, or 6.5. As the actual range is 2,800 yards and the angle 3,360, both less than the tabular, 7 should in this case be taken as the parallax required.

In using the table, note that the angle of obliquity of the point whose parallax is desired is measured from the normal to the front of the battery and is the azimuth of the point

with reference to that normal. The target is always in the first or fourth quadrant and is usually, but not always, so nearly normal to the front of the battery that its angle of obliquity may be neglected. The aiming point may, however, be located in any direction and its angle of obliquity may, therefore, vary from 0 to 6,400.

The values of the parallaxes obtained from the table are used by the battery commander in determining sight deflection, etc., in accordance with the methods hereinbefore explained. In correcting the parallax of the aiming point for obliquity it is usually sufficiently accurate to consider the deflection of the right piece as indicating the degree of obliquity of the aiming point.

Ready Rule for Correcting for Obliquity.—The angle of obliquity, as we have seen, is the angle between the normal to the line of guns and the line of direction of the aiming point. The angle which the latter line makes with the line of guns is necessarily, therefore, the complement of the angle of obliquity, and the cosine of the former is the sine of the latter angle.

From the foregoing we deduce the ready rule that: *the normal parallax multiplied by the natural sine of the angle between the line of guns and line of direction of aiming point or target gives the actual parallax;* or:

$P' = P \times$ sine angle of direction with line of guns.

The natural sines of the angles $22\frac{1}{2}°$, $45°$ and $67\frac{1}{2}°$ are approximately 4, 7, and 9, respectively. But these angles correspond to angles of 400 mils, 800 mils and 1,200 mils respectively.

To illustrate the application of the ready rule, let us take an aiming point directly in rear and azimuths for three targets of 2,000 mils, 2,400 mils, and 2,800 mils, respectively. Suppose T in each case is 10.

A line to the first target makes an angle of 400 mils with the line of guns. $T'_1 = T_1 \times$ sine of 400 mils $= 10 \times .4 = 4$.

A line to the second target makes an angle of 800 mils with the line of guns and $T'_2 = T_2 \times$ sine of 800 mils $= 10 \times .7 = 7$.

A line to the third target makes an angle of 1,200 mils with the line of guns and $T'_3 = T_3 \times$ sine of 1,200 mils $= 10 \times .9 = 9$.

Thus, we see that as the angle of direction approaches the normal the difference between the normal and the actual parallax grows less.

But suppose the azimuth be 2,200 mils. For 2,000 mils the natural sine of the angle of direction with the line of guns is that of an angle of 400 mils or .4, and for an azimuth of 2,400 mils with aiming point in rear the natural sine of the angle of direction with the line of guns is .7. Therefore, the natural sine of the angle of direction for an azimuth of 2,200 mils, or an angle half-way between 2,000 mils and 2,400 mils, is approximately half-way between .4 and .7 or .55.

The only figures that it is necessary for an officer to remember in correcting for the obliquity of the aiming point and the target are:

Angle of Direction with Line of Guns.	*Multiply Normal Parallax by*
400 mils	.4
800 mils	.7
1,200 mils	.9

Problem.—The line of guns runs east to west; the aiming point is due southwest and the azimuth is 3,400; P is —10 and T is 4. Correct for obliquity.

Solution.—The direction of the aiming point is at an angle of 45° or 800 mils, in the lower left quadrant, with line of guns. For 800 mils the proper correction figure is .7, and

$$P' = P \times .7 = -10 \times .7 = -7 \text{ or}$$

Corrected parallax of aiming point = —7.

The direction of the target is at an angle of 1,000 mils in the upper right quadrant with the line of guns. For 800 mils the correction figure is .7 and for 2,200 mils it is .9; 1,000 mils

is midway between 800 mils and 200 mils. Therefore the correction figure is taken as .8:

$$T' = T \times .8 = 4 \times .8 = 3.2 \text{ or}$$
$$\text{Corrected parallax of target} = 3$$
$$P = -7 \quad T = 3$$
$$D = A + n\,(P - T)$$
$$= 3{,}400 + 10(-7-3) = 3{,}400 + 10(-10) = 3{,}400 - 100 = 3{,}300.$$

Whereas, if there had been no correction for obliquity the following result would have been obtained:

$$D = A + n\,(P - T)$$
$$= 3{,}400 + 10\,(-10-4) = 3{,}400 + 10\,(-14) = 3{,}400 - 140 = 3{,}260.$$

Thus an error in deflection of 40 mils would have been made and, since the range is 7,000 yds. when $T=3$, the projectiles would have carried 280 yards to the right of the target.

CHAPTER III

RANGE AND RANGING

The range is the distance of the target from the guns. This range must be distinguished from the ballistic range. The latter may be shorter or greater than the former. The ballistic range depends upon the elevation of the gun and the consequent trajectory while the range of the target is not affected by the adjustment of the piece.

Ranges for light artillery are classified in the Field Service Regulations, 1910 (Sec. 255, p. 159), as follows:—

Distant, Over 4,500 yards,
Long, 4,500 to 3,500 yards,
Effective, 3,500 to 2,500 yards,
Close, Under 2,500 yards.

A "point blank" range is one which requires no elevation on the part of the gun, or it is the distance a projectile will travel in a straight line regardless of the tendency of gravity to pull it toward the earth.

The extreme range of a piece is the maximum distance the gun is capable of throwing a projectile. Distant ranges are often erroneously spoken of as extreme ranges.

The maximum effective range of a 3-inch gun is 3,500 yards. The maximum range at which the piece is effective is from 7,000 to 7,500. This distinction should be borne in mind.

Range may be determined by means of range-finding instruments, by the B. C. telescope and a measured base (Trigonometric and Geometric Calculations), by the use of scaled

maps, by sound, and by estimation. Upon the accurate determination of range all other calculations depend, even those for direction when the parallax method is employed. The distance to the aiming point may be determined in the same manner as the range.

The velocity of sound at a temperature of 50° F. is about 1,110 feet per second. The velocity increases about a foot per second for each degree of temperature. The velocity is also affected by the wind, but if we multiply the number of seconds from the time the puff of smoke from a shrapnel is seen to the time the explosion is heard by the figure 1,100 the result will be the range in feet.

The formula for the calculation of velocity of sound through air, when t = temperature in degrees Centigrade, is:

$$v = 1{,}090 \sqrt{1 + .00366\,t}.$$

By constant practice it is possible to gain the ability to estimate distances very closely, and it is imperative that an artilleryman should acquire this ability. When the range is estimated, the estimation is verified by trial shots before fire for effect is commenced.

The adjustment in range involves the determination of a range setting which will cause the mean trajectory to pass through the target, or, if this is not practicable, the range settings corresponding to the front and rear limits of a zone which surely contains the target.

The adjustment of the range is preferably based upon the observation of percussion bursts. If the ground in rear or in front of the target or registration mark can be seen, the target must be bracketed between such bursts. If the ground cannot be seen, then the target must be bracketed between low bursting time shrapnel.

It is rarely possible from a position near the guns to estimate with any accuracy the amount of the error in range. Such estimates are usually too small and timid, and insufficient

changes in the range are consequently made. Delay in adjusting the fire thus often results.

Attention should rather be concentrated on deciding whether salvos or shots are short or over, and on quickly inclosing the target with fire which is surely short and fire which is surely over.

By gradually narrowing the bracket thus determined an accurate adjustment may be secured.

A salvo is termed short (—) if the majority of its bursts are short, over (+) if the majority are over, and bracketing (+) if half are short and half are over. Bursts at the target may be included either with the shorts or the overs, as the circumstances dictate.

If the bursts of a bracketing salvo occur on graze, the indication is that the range of the salvo was correct; if they occur in air, that the range was approximately correct, but somewhat too great.

If the sense of a salvo cannot be definitely decided upon, it should be noted as doubtful (?) and disregarded.

The observer should train himself to decide quickly upon the sense of a salvo as short, over, bracketing, or doubtful. It may be necessary, however, to allow time for the smoke to form and reveal its relative position with respect to the target.

If the observer is at a considerable elevation above the target, or the target is on ground sloping toward the observer, the sense of a salvo (short or over) may usually be recognized readily by noting the relative position with respect to the target of burst on graze or fragmental hits from bursts in air.

But if the target and its vicinity cannot be seen from a superior elevation, if the ground near the target is at about the same elevation as the observer, or if the ground in front or rear of the target cannot be viewed, the deductions as to the sense of the salvo are to be formed especially from the manner in which the puffs of smoke from the bursts appear with respect to the targets.

A burst on graze causes a column of smoke and dirt to be thrown up from the ground, In the case of a shrapnel this column is relatively small and fugitive; in the case of a shell it is large and remains visible for some time.

A burst in air produces a ball of smoke which ordinarily remains together for some time.

The bullets and fragments from a burst in air knock up a considerable amount of dirt and dust if they strike dry soil; on wet soil splashes of mud are knocked up by the shrapnel case and large fragments. In either case valuable indications are thus furnished as to where the trajectory prolonged reaches the ground.

If the target is silhouetted against the smoke of the burst, the range may always be considered as over, whether the burst occurred in air or on graze.

If the target is obscured by the smoke of the burst, the range may be considered as short; but in the case of a burst in air the burst must be low in order to warrant this conclusion.

If the target is indistinct and of about the same color as the smoke, it may be less visible against the smoke as a background than against its natural background. A burst beyond the target may, for this reason, sometimes seem to obscure the target and hence be judged short, when it is in reality over. On the other hand, some targets become very much more visible if projected against a smoke background.

If the wind is blowing up or down the range, a decision should be formed quickly as to the relative position of the smoke with respect to the target. But if the wind is blowing across the range it may be better to wait until the smoke has drifted across the front or rear of the target. To secure this latter result it may be desirable to direct the fire for adjustment at the windward flank of the target.

It is necessary to study carefully the ground near the target and locate ravines or hollows which might catch and hide the bursts of projectiles. The smoke from such bursts is apt

to rise and reveal itself after a time, but false deductions may be drawn from it. Thus the smoke from a burst short of the target may have become so much dissipated by the time it appears that the target may be seen through it and the impression produced that the target is silhouetted against the smoke. Moreover, if a strong cross-wind is blowing, the smoke when it appears will probably be at some distance to the flank of the actual point of burst, and erroneous conclusions as to the direction of the salvo may thus be reached. Such false deductions may be avoided, however, if the lay of the ground is appreciated and taken into consideration.

In adjusting fire upon a crest great care must be taken to reach this crest and not be deceived by a crest parallel to the crest sought, but short of it. In rolling country such an intermediate crest is often present, and it may merge itself into the background formed by the higher ground in its rear, and hence escape detection, while, as a matter of fact, there may be a broad valley or depression between the two crests. Shots which strike on the near side of the intermediate crest may be taken as establishing the short limit of the bracket, while shots which pass over the intermediate crest, burst low or on graze in the valley between the two, and are lost, may be considered to have cleared the further crest, and hence may be taken as establishing the long limit of the bracket. Such deceptions may be avoided by obtaining bursts in air on the line joining observer and the crest sought. If the ball of smoke is cut in two by the crest and the crest clearly defined against it, the shot is over, while if the crest is concealed by the smoke the shot is short. The short bursts may often serve to reveal the existence of the intermediate crest by causing the latter to be silhouetted against the smoke.

The existence of unexpected ravines and hollows may sometimes be deduced from the fact that, while bursts in air are seen, the points of impact of the fragments with the ground are not revealed by the dust and dirt knocked up.

If the sun is shining, information as to the sense of bursts in air may often be obtained by observing the shadow on the ground of the ball of smoke produced by the bursts. The height of the burst and the position of the sun must, however, be taken into consideration.

If the sense of the burst or bursts is doubtful, circumstances must decide whether to repeat the salvo or round or to change the firing data for the next salvo or round.

If smoke or the fire of other batteries has interfered with observation, a salvo concentrated upon some prominent part of the target may be of assistance.

If the doubt was occasioned by the fact that the bursts were in air and high, it may be well to merely diminish the corrector for the next salvo. The sense of such salvos may often be determined, however, by observing the points of impact of the shrapnel cases.

Fig. 1.

If a salvo is lost, the projectiles have probably burst in a ravine or behind some intervening cover. If the smoke of the bursts does not rise and become visible after a few seconds, the lay of the ground will determine whether to increase or diminish the range or to merely increase the corrector so as to obtain visible bursts in air. Definite information may generally be most quickly obtained in such cases by securing time bursts just above the level of the crests or other cover.

The foregoing remarks, taken from the Drill Regulations, are pregnant with suggestion based on actual experience, and should be studied carefully. While it is impossible, on paper, to consider a case of bracketing subject to the varied conditions of actual practice, it will be well to illustrate a normal case.

Suppose, in Fig. 1, that T is the target and G the gun and that the estimated range is 3,600 yards. The first shot or salvo gives an over burst. The great danger is that the observer will endeavor to save time by an attempt to adjust with

the next shot. Almost invariably the effort will result in a waste of both time and ammunition. When the first shot is over the range should be reduced 400 yards. Suppose this shot is over. The next range would be 2,800 yards. If this shot is short the bracket has been secured. The original bracket is 400 yards and should always be split, however close the short shot may appear, unless the fire is adjusted. The next range would be 3,000 yards and adjustment would be complete provided a 1-mil height of burst had been secured. The corrector should then be raised to give a 3-mil height of burst and fire for effect commenced.

If in ranging by trial shots or salvos, the bursts are not visible, it may be that the terrain between the observation station and the target is such (dense thickets or deep folds in the ground or the two combined) that the sense of the shots

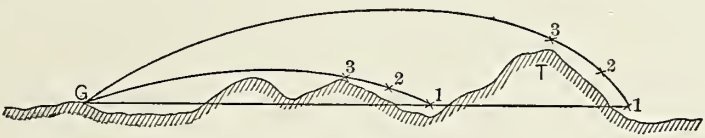


FIG. 2.

cannot be determined. All that can then be done is to be assured that the estimate of the range is as close as possible, check up the angle of sight, and raise the corrector until the burst appears. With the sense of a visible burst determined a bracket can then be secured and adjustment follows. The corrector should be boldly raised, not less than 5 points at a time. Smaller alterations very generally result in the waste of too much ammunition even if time is of no importance.

Let us suppose now that we are firing at T, in Figure 2, and that the first shot is lost; corrector 28, range 4,000 yds.

If we raise our corrector to 33 and still get no burst, the shot may be over 2 or short 2. If the next shot with corrector 38 gives a burst at 3 with the same range it is very probable that we will detect from the height of burst above the target

that our range is too great. At any rate, we will at once bracket and get a short.

Now if the burst were secured with corrector 38, considerably short of the target at 3, on the third shot we would hold at corrector 38 and increase the range 400 yds. until we got a bracket. If we had raised the corrector a point or so at a time it would have taken many more rounds to adjust.

In practice the difficulty of adjusting is increased by the error of the fuse. When the fuse is set for a 1-mil height of burst, from $\frac{1}{2}$ to $\frac{1}{4}$ of the shrapnel fired will burst on graze, and with a fuse set for a mean height of 3 mils about 1/10 will burst on graze. Trial salvos in rugged country are therefore more satisfactory than single shots, for one or more bursts will almost always be secured at the mean height in spite of the error of the fuse.

Under the heading of Range the corrector will not be treated further, as a special chapter will be given to the subject.

Depending upon the nature of the target and upon the accuracy with which the adjustment has been secured, the fire for effect may be of two general kinds, viz.: (1) Fire at a single range, and (2) Fire at successive ranges (or searching fire).

Fire at a single range is appropriate when the firing data for the enemy's position have been determined by previous fire. Thus it is adapted to the attack of all stationary targets upon which an exact adjustment has been secured, or for the attack of moving targets as they reach a position upon which the fire has been previously registered. If the fire is properly adjusted, the necessary effect may be produced with the minimum expenditure of ammunition.

Fire at successive ranges is appropriate when it has been impracticable to secure exact adjustment upon the target. Due to uncertainties of observation, especially at long ranges, exact adjustment is often difficult of attainment; within the time allowed by the tactical conditions it may be impossible

of attainment. In such cases the preferable course is to inclose the target within the smallest limits that can be determined with surety and reasonable promptness, and then to search the area thus inclosed by fire at successive ranges.

If possible, a 100-yard bracket is always obtained, and the fire is delivered at the short, the mid, and the extreme ranges of this bracket until the most effective range can be determined. Whatever the limits determined, however, the fire is closely observed, ranges which are evidently ineffective are rejected, and the area to be searched thus gradually reduced to the smallest possible limits.

Weldon Range Finder.—The object of these lectures is not to improve upon the excellent service manuals, regulations, etc., with which the field artilleryman is supplied, but merely to elucidate the principles upon which the prescribed methods are based, for if the reason for each step is understood the prescribed methods are much simpler to understand.

Before the Weldon Range Finder can be intelligently employed the observer must have some slight knowledge of optics. It is true he may learn to use the instrument successfully in a mechanical way but sooner or later he will become lost, for he is necessarily working in the dark.

If a beam of the sun's rays AB (Fig. 3) be admitted through a small hole in the shutter of a dark room, and allowed to fall on a mirror or a polished plane surface, it will be seen to continue its course in a different direction BC. This is an example of reflection.

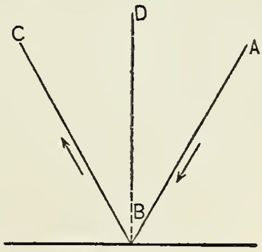


Fig. 3.

AB is called the incident beam, and BC the reflected beam. The angle ABD contained between an incident ray and the normal is called the angle of incidence; and the angle CBD contained between the corresponding reflected ray and the normal is called the angle of reflection. The plane containing

the incident ray and the normal ray is called the plane of incidence.

The reflection of light from polished surfaces takes place according to the following laws:—

1. The reflected ray lies in the plane of incidence.
2. The angle of reflection is equal to the angle of incidence.

These laws must be constantly borne in mind in order to understand the phenomena of reflection.

Now suppose the ruled portion of Figure 4 represents a plowed field, the unruled portion a smooth surface, and that a company of infantry is marching in the line *aa*. The two flanks are on a line with each other. It is obvious that as the

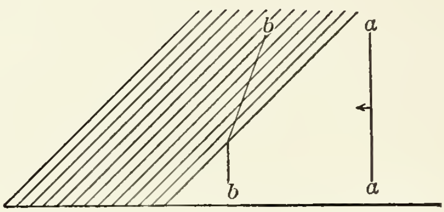


Fig. 4.

line advances, *bb*, a portion of the men will be marching in the plowed field while the left is still advancing on the smooth ground. If the left continues at the same rate, the right will fall behind somewhat, due to the roughness of the ground. This is exactly what happens to a ray of light when it strikes a denser medium. The ray is deflected from its original direction. We have all seen how the direction of a sunbeam is changed by a window-pane. The phenomenon is known in optics as refraction.

Refraction then is the deflection or bending which rays of light experience in passing *obliquely* from one medium to another; for instance, from air into water. Refraction due to water is illustrated by trying to strike a fish with a spear. The fish is never quite where it appears to be, unless one stands

immediately above it. If the incident ray is perpendicular to the surface separating the two media, it is not bent, but continues in its original course. And so would the troops keep in line if they all struck the ploughed field at the same time.

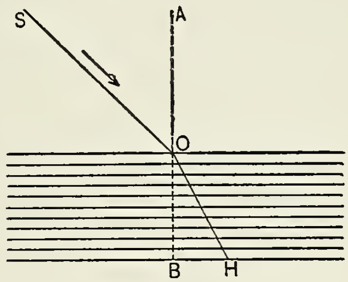


Fig. 5.

The incident ray being represented by SO (Fig. 5), the refracted ray is the direction OH which light takes in the second medium, and of the angles SOA and HOB, which these rays form with the normal AB, to the surface which separates the two media; the first is the *angle of incidence*, and the other the *angle of refraction*. According as the refracted ray approaches or deviates from the normal, the second medium is said to be more or less refracting than the first.

The fluid envelope of the earth, or the atmosphere, is so much denser than the rarefied space beyond that the light from a star is refracted and the star is not actually where it appears to be.

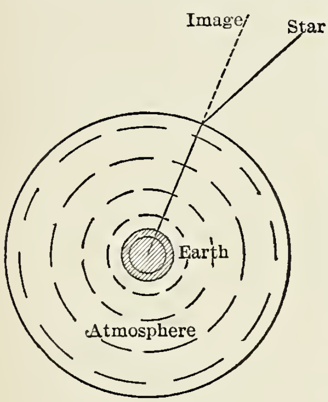


Fig. 6.

Now if a piece of transparent glass or quartz with ground plane faces be used as a medium, refraction occurs; the change of direction of the light depending upon the relative positions of the faces of the refractory medium. Such a medium is called a prism, the word *prisma* meaning something sawed, from the Greek verb, *prizein*, to saw. Optical prisms are usually sawed and ground from the material of which they are composed.

The laws of refraction are such that the angle of refraction

of a triangular prism is equal to the angle between the faces or the inclination of the sides.

Thus, in Figure 7, if O be a luminous point or a visible object, the ray is refracted at D and is deflected to K in passing through the denser medium, just as was the line of troops by the plowed field. At K the ray passes into the air, a less refractive medium than glass, and again changes direction.

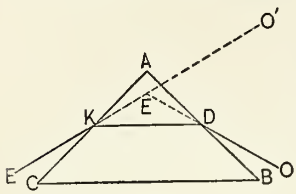


Fig. 7.

The light is thus refracted twice in the same direction, first toward the base of the triangular prism, so that to the eye which receives the emergent ray KE, the image appears to be at O′ instead of at O. O′ is called the virtual image. The word virtual is used because it means, not in fact, not actual, but equivalent so far as effect is concerned.

Objects seen through a triangular prism always appear deflected toward its summit, A. The angle between the incident ray OEO′ expresses the deviation of the light and is called the angle of deviation. This angle not only depends upon the angle of refraction but upon the angle at which the ray enters the prism or the angle of incidence.

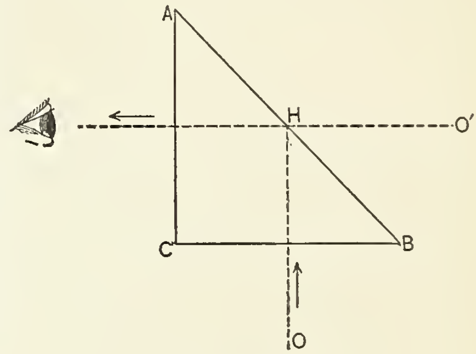


Fig. 8.

An isosceles right-angle prism clearly illustrates the fact that the angle of deviation is equal to the angle of refraction or the angle between the faces. (Figure 8.)

Let ABC be the principal section (a section perpendicular to its edge) of such a prism; O a luminous object; and OH a

ray at right angles to the face BC. This ray enters the glass without being refracted, because it is normal to BC. It makes with the face AB an angle equal to B—that is, 45°. (In an isosceles right-angle triangle two of the angles are 45°.) The ray OH undergoes, therefore, at H total reflection, which imparts to it a direction HI (since angle of reflection equals angle of incidence) perpendicular to the second face AC. Thus the hypotenuse surface (AB) of this prism produces the effect

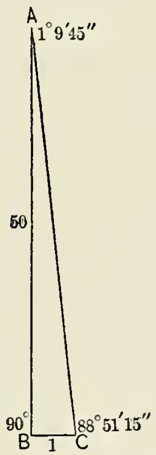


Fig. 9.

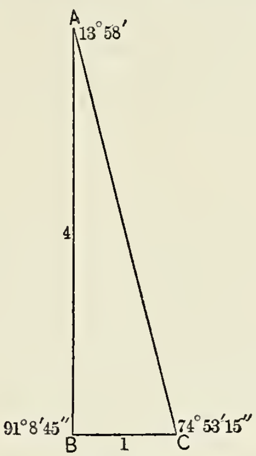


Fig. 10.

of the most perfect plane mirror, and an eye placed at I sees the virtual image O′ whereas the object is at O. The foregoing principles of reflection and refraction are made use of in the Weldon Range Finder, which may now be better understood.

The Weldon Range Finder is a small hand instrument for use in measuring ranges, a full description of which is published in pamphlet form by the Ordnance Department.

The main feature of the instrument is a combination of three small flat triangular prisms assembled one above the other with their principal sections parallel to each other.

If we erect a right-angle triangle (Fig. 9) with a base 1/50 of the altitude, the other two angles will be 88° 51′ 15″ and 1° 9′ 45″.

And if we erect an obtuse-angle triangle, (Figure 10), with an angle of 91° 8′ 45″ included between two sides, one four times as long as the other, the other two angles of the triangle will be 74° 43′ 15″ and 13° 58′.[1]

The first prism of the Weldon Range Finder is so arranged as to reflect an angle of 90°. In other words, it deflects the virtual image through a right angle.

Hence, if the observer at the B. C. Station holds the prism in a vertical position the object (Figure 11) appears in the

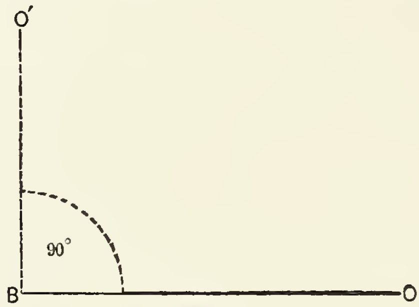


FIG. 11.

direction BO′ instead of at O. Knowing that this prism is made to reflect an angle of 90°, he is able to lay off a perpendicular to BO by marking the direction BO′.

The second prism reflects an angle of 88° 51′ 15″.

Therefore, if the observer, using this prism, moves backward to I (Figure 12) where he brings the virtual image O′ into coincidence with B or any point on a line drawn from B perpendicular to BO, the distance BI will be 1/50 of BO or the range.

[1] There are 360° in a circle, 60′ (minutes) in a degree and 60″ (seconds) in a minute. Angles, as we know, are measured in degrees. Minutes and seconds are simply fractions of a degree.

The third prism reflects an angle of 74° 53′ 15″.

Therefore, if the observer using the prism, moving backward to I (Figure 13), brings the virtual image into coincidence with B, he knows that he is $\frac{1}{4}$ as far from B as O is from B.

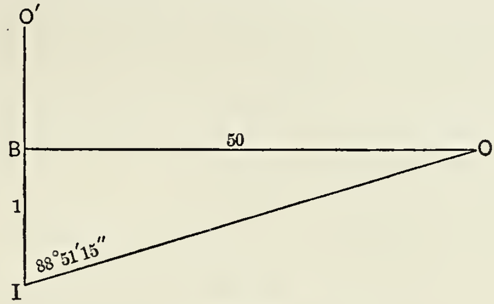


Fig. 12.

With a full understanding of the foregoing, the various methods of necessary ranges as set forth by the Ordnance Department in the Range Finder Pamphlet should appear very simple.

The discussion of the laws of reflection and refraction will

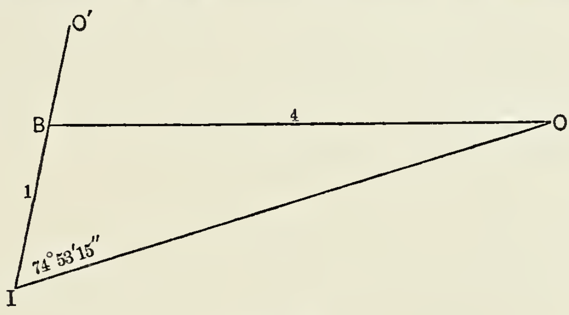


Fig. 13.

serve to impress upon the mind the absolute necessity of holding the prisms in a vertical position to attain any degree of accuracy in determining the range. It also explains the movements of the virtual image.

CHAPTER IV

ANGLE OF SITE

We have seen that the angle of sight in ballistics is the angle between the line of sight and the horizontal. The angle of site in practical gunnery is the same as the angle of sight. If the definition of the word *site* be borne in mind, there should be no difficulty with the angle of site. The site of an object is its position, location, or situation. One object may be situated either higher or lower than another, or at the same elevation. Therefore, the site of a target may be at a higher or lower elevation than that of the guns and the B. C. station, and the site of the latter may be higher or lower than the site of the target and the battery, or they may all three be at the same level. The elevation of the site of the target with respect to the guns must be accurately determined and the angle made by a straight line from the site of the target to the right gun with the horizontal is the angle of site.

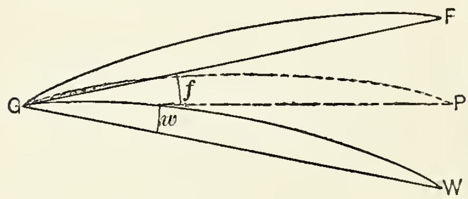


FIG. 1.

Suppose a gun were located at G (Fig. 1) and that the ranges to the fort F and work W were the same. If the range merely were given, the trajectory would be GP, with point of impact at P. Neither the fort nor the work would be struck although the projectile had sufficient range to hit either.

Now if the piece were so elevated that the trajectory passed through F, the range being the same, the straight line from the target to the piece would make the angle f with the horizontal.

A. S. of $F = f$

f is positive (+) because an angle of elevation.

If the piece were so depressed that the trajectory passed through W, the range being the same, the straight line from the target to the piece would make the angle *w* with the horizontal.

A. S. of W $= w$

w is negative (—) because an angle of depression.

The quadrant on the gun is so arranged that when the target is on the same level with the gun the trajectory will pass through the target, no matter what the range, when the instrument is set at 300 mils. The normal angle of site then is 300. For all readings less than 300 the gun is depressed, and for all over it is elevated, after the piece is set for the proper range.

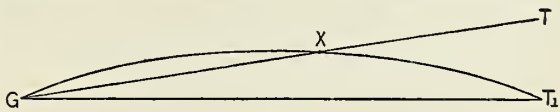


Fig. 2.

If the piece were fired (Fig. 2) with A. S. 300, when the gun was below the target, the projectile would strike at T_1, some distance below the target T. If the line GT be taken to represent the surface of the ground the actual point of impact would be X.

And so, if the piece were fired with A. S. 300, when the target was below the gun, the projectile would strike at T′ (Fig. 3) above the target, resulting in a very high burst.

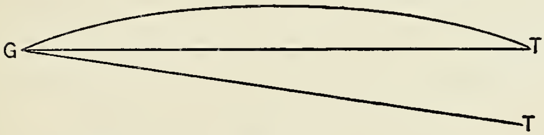


Fig. 3.

Angle of site is easily determined. If the range is 3,000 yds. each mil subtends 3 yds. Suppose the target (Fig. 4) is 63 feet above the guns. 63 ft. = 21 yds. = 7 mils.

If the target is 7 mils above the guns A. S. = 307.

The elevation in mils of any point can be read direct with the B. C. telescope. If the site of the point is higher than the station the reading is 300 + the elevation; if lower the reading is 300 — the depression.

Suppose, from the station B, the reading of the telescope for T is 330 mils and for G is 200 mils. The range of T is 3,000 yds. and each mil subtends 3 yds. Therefore T is $30 \times 3 = 90$ yds. or 180 ft. above B.

The distance of G from B is 200 yds. Each mil subtends 2 yds. Therefore G is $100 \times .2 = 20$ yds. or 60 feet below B.

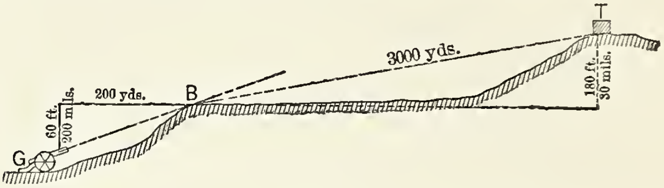


Fig. 4.

If G is 60 feet below B and T is 180 feet above B, T is $180 + 60 = 240$ feet above G.

The problem now is to compute the proper A. S. for G so that the trajectory will pass through T. Taking 3,000 yds. as the range (G may be on a line with B instead of straight behind), 1 mil subtends 3 yds. or 9 feet. It will take $240 \div 9 = 26\frac{2}{3}$ or 27 mils elevation or an A. S. of 327 for the guns to hit T.

Now suppose (Fig. 5) the B. C. station is higher than both the guns and the target.

The telescope reading for the site of the target is 270 mils.

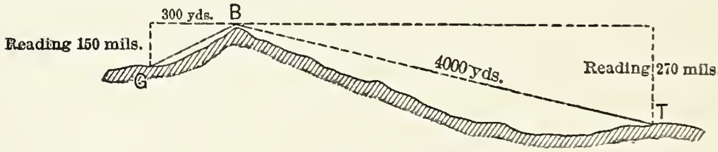


Fig. 5.

There is a depression then of 30 mils. At 4,000 yds. 30 mils $= 4 \times 30$ yds. $= 360$ feet.

The reading for the site of the guns is 150 mils. There is a depression then of 150 mils. At 300 yds. each mil $= .3$ yd. and $100 \times .3$ yd. $=$ 30 yds. or 90 feet.

It is obvious then if T is 360 feet below B, and G is 90 feet below B, that T is 270 feet below G.

270 feet = 90 yds.
1 mil at 4,000 yds. = 4 yds.
Then T is $90 \div 4 = 22.5$ mils below G, or
A. S. $= 300 - 22.5 = 277.5$.

By means of the foregoing solution we arrive at a general formula for the calculation of angle of site from the B. C. station which is as follows:—

$$\text{A. S.} = 300 - \left(\frac{\frac{L_g - L_t}{R}}{1{,}000} \right)$$

L_g = level of gun $\quad$ L_t = level of target
R = range $\quad$ 300 = Normal Reading.

If values be substituted in this formula the result will be the same obtained before. All distances must be in yds. and depressions must be given negative values (−). The solution then with the formula is as follows:—

$$\text{A. S.} = 300 - \left(\frac{\frac{L_g - L_t}{R}}{1{,}000} \right)$$

$L_g = \quad 90 \text{ feet} = \quad 30 \text{ yds.} = -\ 30$
$L_g = \ 360 \text{ feet} = 120 \text{ yds.} = -120$
$R = 4{,}000 \text{ yds.} = 4{,}000.$

$$\text{A. S.} = 300 - \left(\frac{\frac{-30 - (-120)}{4{,}000}}{1{,}000} \right) = 300 - \left(\frac{-30 + 120}{4} \right)$$

$$= 300 - \left(\frac{90}{4} \right) = 300 - 22.5$$

A. S. = 277.5

The importance of accurately determining the angle of site is illustrated by Figs. 6 and 7. In Figure 6 the target is at T but an error in the angle of site (a) causes the trajectory to pass through GT′X instead of to T, GT′ being same curve as GT. The effect in this case is to lengthen the range to the

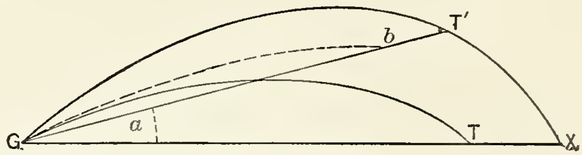


FIG. 6.

extent of TX, which upsets all calculations for corrector as we shall see later.

Let us suppose the first salvo (Fig. 6) results in high bursts at T′. If the corrector were lowered the bursts would occur along the trajectory toward X and all beyond the target. Suppose the original corrector were retained and the range shortened in the effort to get a 1-mil height of burst. The bursts would recede toward G and a burst might be secured at some such point as b that would be effective. It would be too high for the best results, however, and in the meantime

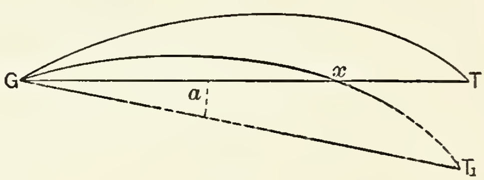


FIG. 7.

there has been a useless waste of ammunition and possibly a disclosure of position.

If the error is one of depression the result is even more disastrous.

Let a, Fig. 7, represent the error in angle of site and suppose that the trajectory passes through the points GxT_1 to

T_1, a point below the target T. Impact would occur at x if the line GT is the surface of the ground. Hence we would get a burst on graze until the corrector had been raised to draw the burst past the point x of the trajectory. This so shortens the range as to make the projectile ineffective.

The effects of the errors are greatly exaggerated in the figures. The nature of the effect from such errors, however, is more forcibly impressed upon the mind. Very slight errors would cause perhaps no appreciable loss of effect from shrapnel.

At medium ranges a change of 4 mils in the angle of site produces a change of about 100 yds. in range. If the angle of site used is too great the range is increased, and if the error is the other way it is shortened.

It must be constantly borne in mind that error in angle of site lengthens or shortens the range, and causes bursts on graze or too high bursts and bursts beyond the target.

CHAPTER V

CORRECTOR

Let GOT (Figure 1) be the trajectory for the range GT. The perpendicular O_1O to the highest point of the trajectory is the maximum ordinate of the trajectory. Angle d is the angle of departure and angle f is the angle of fall.

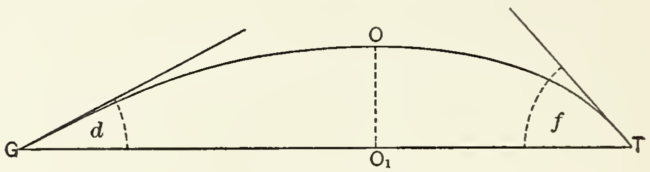


FIG. 1.

If the fuze is set for the range GT by means of the fuze setter, theoretically the projectile would burst at T, and a burst on graze would result; from the very nature of shrapnel the effect of the projectile would be in a great measure lost. Now if the conditions of the atmosphere were such that the powder train of the fuze burned more rapidly than under normal conditions, or if the fuze were so defective as to cause the bursting charge to explode prematurely or before the projectile reached T, the burst could only occur at some point on the trajectory. The highest point at which it could explode would be O. Under normal conditions then, with the fuze set for a given range, the projectile would burst at the point of impact or at T. The fire with shrapnel would be practically ineffective, as it has not the power of impact which an explosive shell has and yet there would be no dispersion of pellets, the very object for which the shrapnel is designed.

In order to secure the desired result a device is attached to the fuze setter by means of which the fuze may be so shortened as to cause the projectile to burst at a point where the maximum effect from the dispersion of the pellets will be had upon the target. In other words the fuze is altered or corrected.

Let GT′T (Fig. 2) be the trajectory for the range GT. It has been found by tests that the maximum effect upon T will be secured when the shrapnel bursts in front of and about 3 mils higher than the target. Therefore, the fuze is corrected so as to cause explosion at T′, 3 mils above T. The normal correction then causes a three-mil height of burst. On the corrector scale attached to the fuze setter the normal correc-

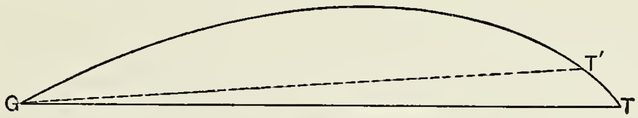


FIG. 2.

tion is marked 30, the scale running from 0 to 60. Every point below the normal lowers the burst one mil and every point above 30 elevates the burst one mil on the trajectory. It is obvious that the course of the projectile is not altered, for the trajectory is determined by the elevation of the piece. Nothing that could be done with the fuze would change the elevation of the piece, and however short the fuze is set the projectile cannot burst higher than its trajectory.

In determining the range of a target it is obviously necessary to burst the projectile as near T as possible, for the puff of smoke resulting from the explosion is the indicator or flag which is waved in front of or behind the target, signaling the error in the range. If the signal is given right at the target the accuracy of the range is easily observed, for the flag or puff either obscures or is partially obscured by the target, whereas if the puff occurs in front of and above the objective, as it does at the normal height of burst, it is difficult to tell

whether a high burst, however effective it may be, is just beyond, immediately over, or at the proper interval short. Hence in ranging, or in adjusting the fire, instead of the normal corrector which gives a 3-mil height of burst, a corrector 2 points lower is used to secure a 1-mil height of burst. If the range and the angle of site are absolutely correct, the fuze perfect, and atmospheric conditions normal, corrector 30 gives a mean or average height of burst of 3 mils, and corrector 28 a one-mil height of burst. If, however, conditions are such that a 1-mil height of burst is secured with corrector 30, then 32 gives the 3-mil height of burst and 32 will have to be employed instead of 30 in firing for effect.

Now, if the mean height of burst is adjusted by trial shots at one range the same corrector is used for other ranges, provided no error in angle of site is made for the latter. Of course

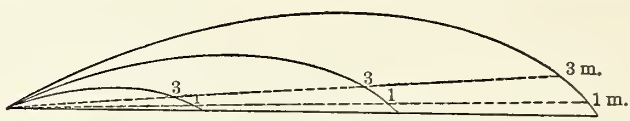


Fig. 3.

the bursts will be higher for longer ranges as the lineal value of the mil in the vertical plane increases with the range. Thus, at 3,000 yards the mean height of burst is 3×3 yards $= 27$ feet; and at 4,000 yards it is 3×4 yards $= 36$ feet. And so a mean height of burst of 1 mil for these ranges would be 9 feet and 12 feet respectively. (Figure 3.)

It is seen then that an increase of n mils in the corrector setting makes a corresponding increase of n mils in the height of burst; a decrease of n mils in the corrector setting makes a corresponding decrease of n mils in the height of burst.

The height of any particular burst may be measured by means of the B. C. telescope. The mean height of a salvo may also be estimated with considerable accuracy, if the bursts as they occur are noted with respect to the horizontal lines in

the field of view of the telescope, and an average is then made. The middle line indicates the normal height of burst; the upper line twice the normal height.

The observer must also be trained to estimate by eye the height of a single burst or the mean height of a salvo.

When the mean point of burst is at the height appropriate during the adjustment (1 mil), from one-half to one-fourth of the shrapnel may, on account of the error of the fuse, be expected to burst on graze. Similarly, when the mean point of burst is at the height appropriate during fire for effect (3 mils), about one-tenth may be expected to burst on graze.

A check is thus afforded on the adjustment of the height of burst, provided a considerable number of rounds fired with the same fuze-setting are observed.

In the accurate adjustment of time fire not only the height but also the interval of burst is important; for projectiles bursting too far in front of the target and those bursting in the air above it produce little or no effect. The interval of burst is correct when both the range and the height of burst are correctly adjusted. Indications that such is the case are: (1) That the bursts on graze bracket the target; (2) that a due proportion of the projectiles burst on graze; (3) that the mean height of burst is about 3 mils; (4) that fragments from the time bursts strike the ground both in front and rear of the target, and that the pattern made by these fragments (as revealed by the dirt and dust knocked up) is close and dense rather than greatly extended; (5) that obvious effect is produced upon the target.

If doubt exists as to the interval of burst it is best to diminish the corrector and get a group of low bursts and bursts on graze.

Observers posted well to the flank of the line of fire may be of the greatest assistance in determining and correcting errors in the interval of burst.

Suppose, then, in an adjusting salvo at 3,000 yards there are one burst on graze and three bursts in air as follows:—40 ft., 50 ft., and 30 ft. high respectively. The average or mean height of burst is $40+50+30\div 3=120\div 40$ feet, or 13 yards. A mil at 3,000 yds. is 3 yds. and a mean height of burst of between 4 and 5 mils instead of 1 mil has been secured. Therefore, if corrector was 28, for first salvo, we should next use a corrector 3 points less or 25. Now suppose a salvo gives 2 bursts 10 ft. in air and 2 on graze; the mean height of burst is correct (about 1 mil), the fire is adjusted, and the corrector

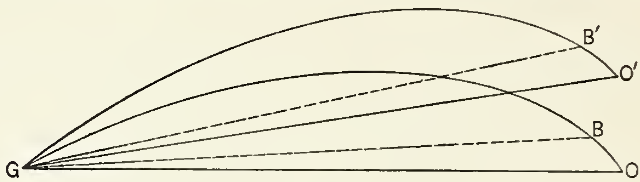


Fig. 4.

for the fire for effect should be increased to 27, which will give a mean height of burst of 3 mils or 9 yds. or 27 feet.

An error in the angle of site, as we have seen, affects the range to the extent of about 100 yds. for every 4 mils of error. It, therefore, interferes with the accurate and prompt adjustment of the height of burst in proportion to the amount of the error.

The influence of the error is illustrated by Fig. 4. Let us assume that the objective is not in the same horizontal plane as the gun, but is at O′, the range being the same for O and O′. In order to make the trajectory pass through O′ it is necessary to increase the elevation of the piece by the angle of site O′GO.

Now if the range GO′ = GO the range ring on the fuze setter is not changed, since it must correspond to the range.

The same corrector which would give a 3-mil burst at B would with the change in angle of site give a burst at B′, for the burst will occur at the same point on the trajectory no

matter through what angle the trajectory may have been revolved. (See rigidity of trajectory: Exterior Ballistics.) Hence the angle B′GO′ = the angle BGO; which means that B′O′ = BO.

Let us assume that the corrector gives a burst B (Fig. 5) at a height of 3 mils above O, situated in the horizontal plane. The trajectory is then GBO. Suppose the objective is at O′, at the same distance as O, but 15 mils above the horizontal plane. Let us assume that the angle of sight O′GO is neglected.

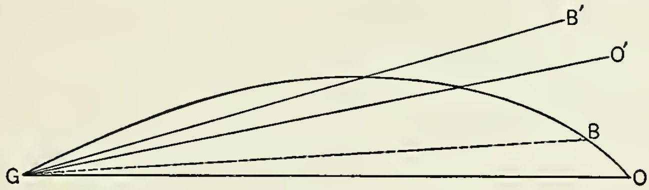


Fig. 5.

The burst would occur at B much too low since B′ is the point 3 mils above O′. The burst must therefore be raised through the angle BGB′; that is, the corrector must be increased by the number of mils contained in this angle.

Now BGB′ = OGO′ since B′GO′ and BGO are both equal to 3 mils. Hence BGB′ = 15 mils or the error in the angle of site. As a consequence of this he must raise his corrector 15 mils, the exact amount by which he decreased the angle of site, the target being taken at O instead of 15 mils above at O′.

A course of reasoning exactly identical would show that for an objective situated, for example, 10 mils below the horizontal plane, if an angle of site too great by 10 mils is used, the corrector will have to be lowered by 10 mils.

The practical results of an error in the angle of site are now easily perceived. To determine the sense of a round, the projectile is made to burst 1 mil above the ground, so that the smoke of the burst will either obscure the target or be obscured

by it. Corrector 28, under normal conditions, will give a mean height of burst of 1 mil.

If the angle of site used is greater than the true angle or in error by too much elevation, the bursts of the first adjusting salvo with corrector 28 will be too high and it will be impossible to judge its sense accurately. If the error in angle of site is an error in elevation of 15 mils the bursts will be 16 mils above the target instead of 1 mil above. Now if the corrections are too timid, it will take many rounds to determine

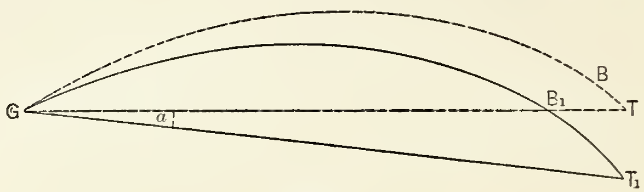


Fig. 6.

the sense of a salvo or of a trial shot and the adjustment of the range will therefore be delayed.

Now if the error in the angle of site is one of depression, that is, if the muzzle of the piece be depressed too much, bursts on impact will result at the point where the trajectory meets the surface of the ground.

T is the actual position of the target (Fig. 6), the dotted line GBT the trajectory at the proper angle of site and B the proper point of burst. The angle a is the error of depression and B_1 the point of impact. If GT is the surface of the ground, the projectile would never reach a point 3 mils above T.

The limitations upon the elevation of burst by raising the corrector are apparent. The burst cannot be secured at a point higher than the trajectory. Hence a large error in the angle of site cannot be compensated for by corrector. Thus in Fig. 6 it is readily seen that, even if a burst were secured on the trajectory GB_1T_1, by raising the corrector so as to draw

the burst above B_1, the projectile would have no effect on the target T if the distance B_1T were greater than the depth of the cone of dispersion.

Generally speaking, when error in angle of site is present, the cause of the error in height of burst is not at first known. If the error in angle of site is small the height of burst may be readily adjusted, but if the necessary correction exceeds the limit of the corrector scale, then the total correction which has been applied to the corrector must be transferred in the same sense, that is, added to the angle of site if 30 + and subtracted from the angle of site if 30—, and the fire continued with the new angle of site and with a corrector about normal.

Suppose, for instance, fire was opened with angle of site 300 and corrector 28; after continuous corrections of 5 points up to corrector 48 still no burst in air is secured. A correction of 20 points has been made. Add the total correction to the angle of site employed. Then continue to adjust, commencing with angle of site 320 and corrector 28.

In the same way, if angle of site is 280 and the bursts are all on graze after a total correction downward of 10 points, the angle of site should be changed to 270 and corrector 28 employed to commence again.

Now let us suppose no burst in air has been obtained with corrector 40 and angle of site 290. Add 12 to the angle of site, which gives a new angle of site of 302, and use corrector 28, which is $40-12$.

There are authorities which hold that the corrector should be applied as soon as the error in angle of site is detected, as above, whether the adjustment may be had through the use of the corrector or not. Others claim that compensation for error in angle of site by change of corrector up to the limit is admissible. The former have the argument in their favor that with the true angle of site the fire is normal, whereas in the latter case an abnormality exists with respect to the trajectory, which does not pass through the target as it should.

When the trajectory passes through the target, relative changes in range and in angle of site may be made, and the normal corrector used, whereas when adjustment has been secured by abnormal corrections of the height of burst, relative changes in range and in angle of site are impracticable. This disadvantage increases with the correction. When the correction is small the disadvantage is of no practical effect.

CHAPTER VI

OBSERVATION OF FIRE

The time required to adjust, in order to secure an effective fire, and the expenditure of ammunition may both be greatly reduced, if, by reconnaissance, the enemy's positions are well determined and if, by auxiliary observers pushed well to the front and flank, information is obtained which will assist in the adjustment of fire.

The searching of areas is never to be resorted to unless it can be definitely determined that the enemy is actually located within the area selected, and unless he would evidently exercise a material influence upon the progress of the combat if left undisturbed by fire.

The officer conducting the fire should be posted where he can observe not only his immediate target, but as much as possible of the terrain liable to be assigned him to attack. Unembarrassed by details of the service of the guns he should devote himself to observing and correcting the fire and adapting its employment to meet the requirements of the situation. He should train himself to form accurate and quick estimates and to act on them with decision and boldness.

To overlook ground which is visible to the officer conducting the fire, as well as for the purpose of assisting generally in the adjustment of fire, free use is to be made of auxiliary observing parties.

Such parties occupy the most favorable observing stations which the conditions of the combat admit. Preferably they are as near the enemy as possible. If near the guns, they are posted usually on the flanks and in elevated positions, if possible; for example, in the tops of trees, on buildings, on artificial towers, etc.

Their special duties are to signal information which will assist in the adjustment of fire and to keep the artillery commander informed of movements of the targets or of our own troops which would affect the employment of fire.

With respect to the adjustment of fire, they indicate especially whether the range is short, over, or correct, whether the interval of burst (distance of point of burst in front of target) is too great, too small, or correct; whether the direction is right, left, or correct.

If large errors in range are made, an observer on the flank of the guns will not usually be able to separate the errors in range from those in direction; in such a case the observer would ordinarily signal the direction only, as right or left, as it appears to him, and the officer conducting the fire, knowing the position of the observer, would deduce the sense of the salvo, volley, etc., in range. If the observer is to the right of the line of fire, shots striking short of the target appear to be to the left, while those striking over appear to be to the right, and *vice versa* if he is on the left of the line of fire.

With respect to movements of the enemy, the observer reports especially: If the enemy abandons his position; if he shifts to the right or left, front or rear, to escape effective fire; if additional hostile troops enter the sector assigned the guns.

With respect to our own troops, the observer makes such reports as to their movements and situation as will enable the artillery commander to best assist them with the fire of the guns.

Arrangements should, moreover, be made with advanced troops of the other arms for the transmission of information which will assist in the adjustment of fire and for the indication as to when fire should be commenced or discontinued.

Sure and definite means of communication must be established between the artillery commander, his observing parties,

and advanced friendly troops. If time admits, telephone communication is provided; but visual signaling must always be relied upon to a greater or less extent.

For observation of fire, for study of the terrain, and for the quick recognition of objectives, good field glasses are indispensable. All officers of the artillery, chiefs of section, and scouts must be equipped with suitable glasses.

At the commencement of the fire it is usually best to watch for the burst of the shots with the unaided eyes, for if a large error is made the burst may not appear in the field of view of a telescope or field glass. After the bursts have been located the glasses may be quickly brought into play, if necessary, and the relative position of the smoke with respect to the target noted.

After the fire has been approximately adjusted the points of burst are observed by the aid of field glasses or the telescope, and all the indications carefully noted which assist in the determination of their relative positions with respect to the target.

Much ingenuity may be employed in observation in general. Before any system can be effective, however, a definite set of signals or means of communication must be established. It is surprising how often a word or a movement of the arm will convey an entirely different meaning from the one intended.

Two approved methods of lateral observation are here given, the first when two observers are employed; the second when a single observer is used.

1. *The case of two observers D. and K., Figure* 1. Each observer (at night each should use two lanterns) faces the battery while at the same time observing the target. Each of them extends his right arm if the shot appears to him to the right of the target, and his left arm if the shot appears to him to the left; both arms if the shot appears to him correct in direction.

Assume that OL is the target.

SHORT SHOTS INCLUDED IN THE ZONE KLOD.

Each shot in the angle KAD is to the left for D, to the right for K. Both extend the arm away from the target.

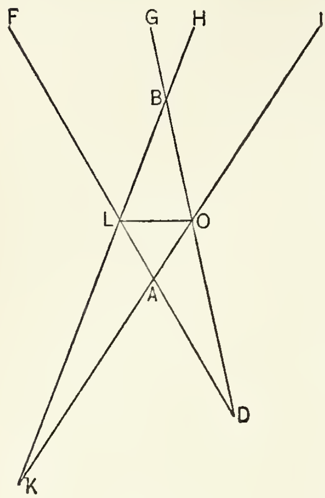


FIG. 1.

Any shot in the triangle KLA is to the left for D, in line for K. The observer K extends both arms; the observer D extends the arm away from the target.

Any shot in the triangle DAO is in line for D, to the right for K. D extends both arms; K extends the arm away from the target. Thus, when both observers extend an arm in the direction away from the target, or when one extends both arms in that direction and the other extends one arm, the shot is short.

SHOTS THAT ARE OVER AND INCLUDED IN THE ZONE FLOI.

Any shot in the angle GBH is to the right for D, to the left for K. Both extend the arm toward the target.

Any shot in the zone FLBG is in line for D, to the left for K. D extends both arms; K extends the arm toward the target.

Any shot in the zone HBOI is to the right for D, in line for K. K extends both arms; D extends the arm toward the target. Thus, when both observers extend an arm toward the target, or when one extends both arms and the other extends the arm toward the target, the shot is over.

SHOTS NEAR THE TARGET.

Any shot in quadrilateral ALBO is in line for both D and K. Both extend both arms.

Doubtful Shots.

Any shot in the angle DOI is to the right for D, to the right for K. One extends the arm toward the target; the other extends the arm away from the target. It is the same if the shot bursts in the angle KLF.

Thus, when both observers extend the arm, one toward the target and the other in a direction away from the target, the shot is doubtful.

To sum up: The shot is over when both observers extend the arm toward the target, or when one extends both arms and the other extends the arm toward the target.

The shot is short when both observers extend the arm away from the target, or when one extends both arms and the other extends the arm away from the target.

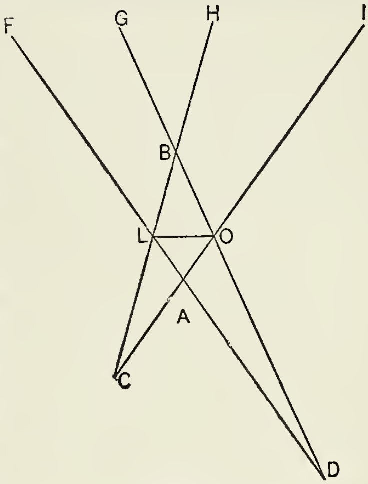


Fig. 2.

The shot is near when both observers extend both arms.

The shot is doubtful when one extends the arm toward the target and the other in the opposite direction.

2. *The case of a single observer.* (Fig. 2): The captain is at C.

Short Shots Included in the Zone CLOD.

Any shot in the angle CAD is to the right for the captain, to the left for the observer D. D extends the arm away from the target.

Any shot in the angle CAL is in line for the captain, to the left for D. D extends the arm away from the target.

Any shot in the angle DAO is to the right for the captain, to the right for D. D extends both arms.

Thus, when the observation of the captain does not agree with that of the observer D, the shot is short if he extends the arm away from the target; it is also short if, D extending both arms, the shot is to the right for the captain.

Shots Over and Included in the Zone FLOI.

Any shot in the angle GBH is to the left for the captain, to the right for D. D extends the arm toward the target.

Any shot in the zone FLBG is to the left for the captain, in line for D. D extends both arms.

Any shot in the zone HBOI is in line for the captain, to the right for D. D extends the arm toward the target.

Thus, when the observation of the captain does not agree with that of the observer D, the shot is over if he extends the arm toward the target; it is also over if, D extending both arms, the shot is to the left for the captain.

Shots Close to the Target.

Any shot in the quadrilateral ALBO is in line for the captain, in line for D.

Doubtful Shots.—Any shot in the angle DOI is to the right for the captain; to the right for D.

Any shot in the angle CLF is to the left for the captain; to the left for D.

To sum up: Whenever the observation of the captain does not agree with that of the observer the shot is over if the observer extends the arm toward the target; it is short if the observer extends the arm away from the target.

If the observer extends both arms, the shot is over if it is to the left for the captain; the shot is short if it is to the right for the captain.

If the observer extends both arms the shot is close to the target if it is in line for the captain.

There is no doubt if, the shot not being in line, the observation of the captain agrees with that of the observer.

CHAPTER VII

POSITION AND THE MASK

Positions are defined as *masked* or *unmasked*, according as they afford concealment or not.

When no concealment is afforded the guns are said to be in an *unmasked position*, and the fire is referred to as *unmasked fire*.

When concealment is afforded the guns are said to be in a *masked position* and the fire is referred to as *masked fire*.

The mask, then, is the intervening object which screens the guns from the view of the enemy.

If the guns are posted behind a mask in such position that the hostile position, or the target, may be seen through the sights, they are said to have *sight defilade*.

If they are posted where a dismounted man can just see the target over the mask, they are said to have *dismounted defilade*.

If where a mounted man can just see the target over the mask, to have *mounted defilade*.

If so that the flash of the guns will be concealed, to have *flash defilade*.

While the drill regulations give 12 feet below the crest of the mask as the point of flash defilade, in practice 20 feet is more satisfactory.

A mask can either be a mere screen, such as a fringe of trees, or a hedge, enabling direct laying to be employed, or it may be such a natural object as a hillside, or a dense thicket, entailing the necessity of indirect fire. In the first case the projectile passes through the mask, in the latter the tra-

jectory must clear the obstacle. It would perhaps be better if concealment of the former character were strictly defined as a screen, the latter only being referred to as a mask, for the distinction is important. If fire is merely referred to as masked, we do not necessarily know whether it is direct or indirect. Therefore, we should designate the fire either as direct fire masked or indirect fire, in order to convey an exact meaning.

Practicability of the Mask.—Much has been written, and grave doubts are entertained, about the practicability of the mask in actual service. Question is raised, of course, more particularly with respect to masked fire against infantry.

In advancing against another body at a distance of some thousands of yards over ground exposed to artillery fire, infantry takes its precautions accordingly, usually assuming a formation in small groups—say from a platoon to half a dozen men. These groups, often several hundred yards apart, advance by rapid rushes of varying length. The Japanese groups are known to have advanced continuously for four hundred yards at amazing speed before lying down, a performance quite beyond the endurance of European troops in general. In view, then, of the unstationary, shifting character of the infantry as a target, much uncertainty exists, especially in the ranks of the infantry and cavalry, as to whether artillery fire is sufficiently flexible to repel an infantry assault when indirect laying is employed. While the Japanese doubt was confirmed by their experiences in the fighting around Liao Yang, we must remember that the guns there used were not comparable in efficiency with those with which the French, English, and our own artillery are now equipped.

The French system of fire against infantry seems to be more flexible than any other, because of the highly independent employment of individual guns, a single gun only being used to fire upon a small group, an appropriate target for the weapon. The danger of a less independent use of the guns in repelling

an infantry assault is the tendency of the battery commander to wait for an opening to use the four guns effectively, whereas such an opportunity may never present itself, or, if it did, it might not be until late in the action when the two infantries were in close contact. Yet indirect fire against rapidly advancing infantry does not seem to be contemplated even in the French system.

The artilleryman observing groups of approaching infantry will notice that they generally come into sight at particular points indicated by the nature of the terrain—woods, hedges, sunken roads, hills, etc.—and, further, that such of these bits of cover as form the longest salients toward him seem the most popular. "Infantry like electricity," says Major Buat, "has a tendency to escape from points." It will also be observed that the current of groups flowing from any particular bit of cover directs itself upon another. Between the two bits of cover each group advances by short rushes; behind it are other groups, some in motion, some stationary, but all transitory.

If we now add that all these streams of groups take their origin at varying distances from the observer—for the patches are scattered irregularly over the ground—we shall have a fairly good idea of the target presented to the battery, a target more or less difficult for direct fire. "It is evident," says Major Buat, "that all the batteries in an army corps would not go far if we should try to assign one to look after every stream of groups, or even every two or three streams. Out of all the batteries thus brought into action, only a few guns at a time would be usefully employed. The rest would be firing upon unoccupied ground, or not firing at all. All this leads us to try to economize both guns and ammunition, and to use a few guns working actively instead of a large number firing slowly and intermittently. One gun should be enough to fire upon a target of a squad or two. This is practically impossible except with direct fire. Can we conceive of anything more

difficult, and more impractical, than a battalion, or a battery commander, calmly perched upon an observing station or tower, indicating the data for a large number of guns firing upon numberless small groups moving at a rapid rate, and frequently disappearing altogether? Indeed, before the data could be transmitted, and the pieces layed, new data would be required."

Based upon the foregoing considerations, and what has actually been seen at maneuvers, the principal objections urged against indirect laying are as follows:—

1. The tendency of field artillery officers to seek the masked position, regardless of the tactical situation and of the end that the guns are called upon to accomplish.

2. The delay in occupying positions and in opening fire, caused by the time taken up in making preliminary reconnaissance and in computing the elements of fire.

The foregoing objections cannot be more ably answered than they have been by Colonel McMahon in a recent article to which the student is referred.*

As regards the first objection, it may be said that the excessive use of cover in maneuvers is, in the general case, caused by the fear of the artillery commander that he will be harshly criticized by the umpires for unnecessary exposures of his command, and that he will be charged up with losses which, fortunately for all those who bear arms, occur only when blank ammunition is used. The slowness may be attributed to various causes, lack of proper training of the personnel, failure to keep in proper adjustment the instruments for the conduct and observation of fire, failure to maintain proper communication between the officer conducting the fire and the firing unit, and, lastly, the tendency, which fortunately is now rapidly disappearing, to make use of coast artillery methods

*Col. John E. McMahon, G. S. C., Infantry Journal, July-August, 1911, "Concerning Masked Fire." See author's article "Concerning Masks," Field Artillery Journal, January, 1912.

in the determination of firing data, with a consequent sacrifice of the essential properties of the rapid-fire field gun. However just these criticisms may be, it should be noted that the objections urged against the use of masked fire in general are not inherent in the system itself, but can be easily overcome by proper instruction and training. The fact also remains that, unless the doubts as to the practicability of masked fire be removed from the minds of infantry and cavalry officers, when war breaks out the field artillery will find itself at variance with the other branches of the mobile army, and the coöperation so essential to success will be entirely lacking. To clear up, if possible, this atmosphere of doubt is the writer's object.

Paragraph 690, Field Artillery Drill Regulations, 1908, states:

"TO POST THE GUNS SO AS TO BE ABLE TO CARRY OUT EFFECTIVELY THE TASK ASSIGNED IS ALWAYS THE FIRST CONSIDERATION IN THE SELECTION OF A POSITION."

Again, paragraph 698 says:

"When it is necessary to bring guns into action quickly for the support of other troops, the main consideration is to get them as promptly as possible to a place from which they can render effective support. In such a case, delay occasioned by the search for technical and tactical advantages is entirely inadmissible."

From this it appears that in our field artillery system the use of masked positions is plainly made dependent on the tactical situation and the purpose that the guns are called upon to perform; and that the artillery commander who seeks cover at the expense of fire efficiency is acting in direct opposition to the spirit of the regulations. On the other hand, the artillery officer who, from a spirit of bravado or a failure properly to estimate the tactical situation, needlessly exposes his guns in the open runs great risk of bringing disaster upon

the troops with which he is serving and at the same time sacrifices uselessly one of the most important properties of the rapid-fire field gun—the power of acting by surprise.

It may be fairly stated that, under the limitations given above, in all engagements of any importance except combats of cavalry against cavalry, the modern tendency is to make masked fire the normal method of procedure. The French, who were the pioneers in all that pertains to modern field artillery, have lately had their drill regulations revised by a commission made up of their ablest officers of that arm. This commission has laid down three great principles governing the employment of field artillery in battle, and the first of these principles is, "Artillery will preferably occupy masked positions." The Germans, who sought for a long time to cover up their deficiencies in material by a pretended contempt for the French methods and stoutly maintained the advantages of the "partially exposed positions," are to-day prevented from acknowledging the truth of the French principles only by lack of funds to purchase the accessories that make effective masked fire possible. The infantry officer should therefore be prepared to face the fire of guns that he does not see and to allow the artillery commander the necessary freedom to decide whether or not the tactical situation demands the placing of the artillery in the open.

It is not expected that the reader will take for granted the dictum that in the general case the masked position is to be preferably sought. The advantages claimed for it are the following:

1. Without sacrificing any of its offensive properties, artillery in a masked position can escape destruction and at the same time preserve its liberty of action. While the cannoneers of a modern field battery are protected from shrapnel and infantry fire by shields, the officers and chiefs of section must necessarily be exposed in the performance of their respective duties. The supply of ammunition must also be affected in

the open. It is therefore certain that a battery exposed in the open to well-adjusted artillery fire will find its effectiveness seriously compromised by grave losses among its officers and non-commissioned officers and by the great difficulty experienced in bringing up ammunition from the combat train. It cannot bring up its horses to move the guns to a more sheltered position without risking annihilation. At the Yalu three Russian batteries posted in the first line attempted to retire before the Japanese advance. The guns had been placed in advance of the military crest and the limbers had to cross the crest to reach the guns. Their losses from the Japanese artillery were as follows:

	Officers.	Men.	Horses.
2nd Battery, 6th Division........	7	79	108
3rd Battery, 6th Division........	1	23	74
3rd Battery, 3rd Division.........	5	86	72
Total.........................	13	188	254

The only recourse for a battery exposed in the open to effective fire from the enemy's guns in a covered position is to cease firing, shelter its personnel, and wait for an opportunity to reopen fire when its adversaries have been forced to transfer their attention to another target by the intervention of a friendly battery. A battery thus pinned to the ground is exposed to the added danger of having its material destroyed by high-explosive shell fire. Against this projectile the shields are helpless, and experiment has proven that, up to ranges of 3,000 yds., the battery that is forced to stand idle in an exposed position under effective shrapnel fire will promptly be reduced to scrap iron, if attacked by well-adjusted shell fire.

2. A battery in a masked position can prepare its fire in advance, thereby reaping the full advantage of its characteristic property of being able to act by surprise. Under the protection of the covering crest, the battery commander recon-

noiters and occupies the position quietly and coolly, undisturbed by the fire of the hostile guns. He can register in advance the zone assigned to him, prepare the firing data for the prominent objects in the zone and thus be ready to open fire quickly against the targets appearing in his front. By a skillful selection of the emplacement of his guns, he can deceive the enemy as to his distance from the crest, and so force him to consume much ammunition in the attempt to locate the position of the guns. If he finds that his adversary is approaching the correct adjustment in range and direction, he can tempoorarily cease firing, thus causing the enemy to believe that adjustment has been secured and to open his fire for effect before the elements of fire have been correctly determined. If ordered to change position he can do so without incurring serious losses among his men and horses.

3. When indirect laying is used, artillery fire can be not only directed upon a target but also shifted to a new objective more quickly and effectively than when direct laying is employed. Based upon target ground experiences, in which a single objective appears at a time and the firing is conducted under favorable circumstances, this may seem a startling statement to make. Let us assume that artillery has taken a position in the open and has been assigned a sector of the battle front. A target suddenly appears in that sector and it becomes necessary for the battery commander to point it out definitely to his four gunners, a task easy enough in the quiet atmosphere of the target ground, but quite another matter in the roar and confusion of battle. In some cases he will have to assemble his chiefs of section and gunners in order that he may make sure that the target is identified. The proper distribution of the fire of the battery, so that the fire of each gun may be directed upon its proper section of the target, must be left to the platoon commanders. Should a new objective appear, the same difficulties are renewed. If the battery were using indirect laying the problem would be much simplified. Before

disclosing his position, the battery commander selects as registration marks a number of prominent objects in the sector assigned him and prepares in advance the elements of fire for these points. As each new target appears he loses no time in attempting to point it out to the gunners. He simply commands for example: "Add 80," or "Subtract 120," correcting the deflection previously used by the angular distance between the new objective and the registration mark or the target upon which the guns were last laid. By proper changes in the deflection difference he can obtain converging or parallel fire, and can open and close the sheaf at will. In this way the chances of error are greatly decreased and much time is saved—the latter a most important consideration when we remember the fleeting nature of the targets that will in general be presented to the artillery on the battlefield.

Turning to the other side of the question, the main objections urged against indirect laying from a covered position are that this method requires too much time for the delivery of fire; that it causes a dead space in front of the covering crest, the extent of which depends on the degree of defilade assumed; and that it entails the separation of the battery commander from his battery, with a consequent loss of control over his men.

As to the first objection, it may be said that indirect laying should not be used whenever there is necessity for a quick entry of the guns into action. Artillery brought up, for example, to drive back a menacing attack already under way should not waste valuable time in an endeavor to secure cover. In cavalry combats, again, the open position and direct fire will be the rule. It is only when the tactical situation permits a careful and deliberate preparation of fire—and this will be the case seven out of ten times in an engagement of any magnitude—that the covered position will be used. Even when so used, there is no good reason why the opening of fire should be unduly delayed. The time

required is a direct function of the training of the personnel. It may be safely said that a skillful battery commander should be ready to begin his fire within five minutes after his guns are in position. The day for elaborate calculations and careful measurements of angles has gone by. The parallax method for computing the firing data is sufficiently accurate for use in the great majority of cases. It is devoutly to be hoped that when the next war comes the spectacle will not be seen of a battery commander sitting down behind the sheltering crest with pad and pencil in hand, pondering over the question whether n is plus or minus, while the infantry is lying in the open anxiously waiting for the sight of the shrapnel bursting over the enemy's lines.

The objection as to the dead space is a more serious one. In considering the subject, however, it should be remembered that generally the artillery will be posted in rear of the line occupied by the infantry, and that, consequently, they will be able to cover the ground in front of the infantry position, even though a dead space exist in front of the guns. This dead space, moreover, is not so serious an objection in the case of artillery supporting an attack as it would be in a defensive position. Skillful dispersion of the guns, by which the dead space in front of one battery may be swept by the fire of another posted on the flank, will help to solve the problem. The fire of heavy field howitzers will be especially useful for this purpose. The dead space may be reduced in extent by occupying the front slope of a second crest, and may be partially swept by firing at the minimum range possible for a given position with a high corrector, thus causing the shrapnel to burst short and high, but the efficiency of the projectile will be considerably reduced by this method. The disadvantages of the dead space may also be reduced by the skillful battery commander who, when making his preliminary reconnaissance, first determines the minimum range at which he will probably be called upon to fire and then selects the degree

of defilade to correspond to this condition. For example, if the tactical conditions are such that he may reasonably expect that the necessity will arise for him to completely sweep the front slope of the covering crest, he will take a position of either dismounted or sight defilade and move the guns up by hand when the critical moment arrives, as was done years ago at Gettysburg and Fredericksburg.

The separation of the battery commander from his battery may possibly affect the morale of the men, but with the excellent field telephone now supplied the field artillery the cannoneers at the guns are always practically within sound of their "master's voice." As a matter of fact, this objection is one based principally on peace conditions; for in time of war the limited space assigned the field artillery of a large army will not permit the battery commander to place his observation station at such distances from the battery as is possible on a target range. Resort will be had to observation towers, or to natural objects in the vicinity of the guns, from which a clear view of the ground in front may be obtained.

As to the question whether masked fire is really practicable, there can be but one answer for the field artilleryman to make. This question was settled once for all in the Manchurian war. The Japanese, even though without a long-recoil gun or any of the standard instruments that now form an essential part of the equipment of a battery, were nevertheless able to fire from masked positions with such effect as to overpower the Russian guns, at first habitually fought in the open. With the excellent instruments for the conduct and observation of fire now furnished our field artillery, effective fire from a covered position is merely a matter of proper training. The infantry may rest assured that the material is all right and that the personnel is seeking by every means in its power to reach that stage of efficiency which will make the field artillery the strong right arm of the infantry in battle.

Position.—An artillery "position" does not necessarily mean a defensible feature of the ground. It merely means the place where the guns come into action, and may be anything from a sunken road or a corn field to a commanding ridge.

It is most desirable that the guns should stand on firm and level ground, free from large stones. Unless the ground is firm the spade will not take hold properly, and the gun will tend to jolt sideways during firing.

If the ground slopes down to the front it is often impossible to get sufficient elevation at the first round, before the spade is imbedded, especially when the target is above the gun.

If the gun be on a steep reverse slope, firing at a low angle of elevation, then the axis of the piece will make a larger angle with the trail and the gun will jump instead of remaining steady on firing.

Large boulders and a rocky soil prevent the spade from taking a fair bearing, and make the gun exceedingly difficult to traverse. The B. C. must give the ground of the position much the same consideration that a mariner gives to his anchorage, that is—will the anchor hold.

Whenever the anchorage, so to speak, is bad, it will be found to save time if the section commanders and gunners are permitted to select emplacements for their pieces before the battery is brought into action.

Direct Fire.—Since the command of a position must be good, the guns are usually posted on high ground. The choice of a position for direct fire will as a rule lie between the forward crest and the rear crest or between the military crest and the actual crest.

In the accompanying figure, the military crest is at M, the actual crest at C, and the rear crest at R. The military crest may therefore be said to be the point of slope from which the greatest command of the foreground, including the underlying terrain, may be had, while the actual crest is at the skyline, and the rear crest is in rear of and below the sky-line.

All of the space from M to O is defiladed against fire from C and is therefore called dead space with respect to the actual crest.

The forward or military crest position gives a better view, and the guns, being below the sky line, are difficult for the enemy to locate, so long as the men keep still. On the other hand, the forward position renders ammunition supply difficult and with the 3-inch gun, which has a long trail with a large spade at the end of it, it is often impossible to get sufficient elevation

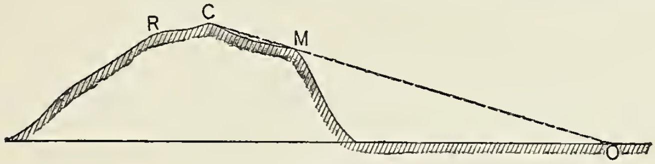


FIG. 1.

for the first round without digging a small trench for the spade. When this is the case and there is no time for trenching, it is sometimes advisable to fire the first round with as much elevation as possible even if insufficient to reach the target, if by so doing the spade will be sufficiently imbedded to give the necessary elevation.

As a rule, the forward crest position makes it easier for the enemy to get the range of the guns, since the sense of ranging shots can be easily determined.

The rear crest position has the serious drawback that the guns must stand above the sky line, and also that the field of view and the field of fire are both inferior to that obtained from the forward crest. The former disadvantage may be minimized by keeping the guns run back until required to open fire; while the latter may be somewhat minimized in so far as view is concerned by keeping lookout men with glasses in front of each flank. The field of fire, of course, cannot be increased to any great extent by running the guns forward. There will always be a large dead space just below the

military crest which the guns cannot search whether posted on the rear or on the actual crest. It will be recalled that Bragg so posted his artillery at Lookout Mountain and that Sherman's and Sheridan's infantry were able to reach the guns without suffering very greatly from their fire.

The slope of descent of a shell at 3,000 yards is about 1 in 6; that of the lower bullets of a shrapnel is about 1 in 5. Now a hill with a slope as steep as 1 in 5 from top to bottom is rarely to be met with. It follows that it is practically impossible to obtain cover for the limbers and wagons by posting them at the foot of the hill close behind the guns.

Since many of the shell fired at the guns will burst quite 200 yards over, and since the shrapnel bullets are effective 300 yards beyond the point of burst, it follows that the line of limbers and teams must be at least 500 yards distant if placed in rear of the guns, or still further if the enemy's range is short. It is sufficiently obvious that it is not desirable to place the limbers and teams and the reserve in rear of the battery under any circumstances if it can be avoided, for if they are far enough to the rear to be safe from hostile fire they are too far away to permit of celerity in the change of position. The same consideration, of course, which renders the placing of the limbers in rear of their own guns undesirable holds true with respect to the placing of the limbers in rear of other batteries on the flanks of the battery to which they belong. If the line of guns constituting the group is a very extended one, however, it will be necessary to place the limbers of an interior battery in the rear of some of the guns. In such a case good judgment as to the best protection available must be employed.

Alignment of Guns.—There is one other point which may be noted here, for it applies to every position which guns occupy where there are several in line. It is sometimes thought, and possibly in one respect with justice, that exact drill and dressing are of but little importance nowadays to artillery, or that, at any rate, too much attention has been hitherto paid to them.

In order, however, to ensure that the full activity of every gun shall be available for every emergency, it is desirable that they take up a precise alignment; otherwise it may happen that when fire has to be turned to a flank some of the guns may mask or at least interfere with the fire of others. Thus, if several guns be drawn up upon an uneven or slightly curved line, and it should be necessary to shift the sheaf of the battery through a considerable angle to the right or left, a gun in the center, if too far advanced, may mask the fire of those on the flanks. Similarly, if the line of guns be curved inwardly, those in the center may find their fire interfered with by those that are more advanced. These considerations are of even more importance in connection with the batteries of a battalion.

To facilitate ranging, it is desirable that the correct intervals between guns and batteries be observed. The crest line of the height occupied should also run, if possible, at right angles to the proposed line of fire; otherwise the position may be enfiladed from some position of the enemy other than that being fired upon.

When it is impossible to find a suitable position at right angles to the line of fire, it must be considered whether it is better for all the pieces brought into action at a particular position to be echeloned along the crest line affording the position, or whether the batteries should be placed at right angles to the line of fire, and themselves as units be in echelon while their guns are in line.

Entrenchments.—In entrenching a gun, the first thing to see to is that its fire can be directed upon any target in the sector of fire. If an epaulment or a gun pit is used, there must be sufficient space to permit a full traverse of the gun.

Protection for the detachment is best provided by digging deep trenches on either side of the gun, in which the men, when not actually serving the gun, can sit with their backs to the parapets, their heads being at least a foot below the crest, which must be thick and solid. It must be remembered

that the angle of descent of shrapnel bullets, at medium ranges, is about 1 to 5, so that protection is only obtainable close under the parapet, unless overhead cover can be constructed. On no account must cover be constructed on the sky line or actual crest. The best position for gun entrenchments is usually the military crest. Epaulments and gun pits, or the guns themselves when unprotected, should be obscured by brush, and the natural features of the ground should always be taken advantage of when possible, even if the prescribed spacing of the guns has to be disregarded. Of course, the intervals cannot be so largely increased as to render the calculations for deflection impractical except for the right piece.

With ten gunners digging, and three drivers cutting sods, and hauling them on the limbers when necessary, it takes from three to four hours to provide good cover for a gun, or double this time to construct overhead cover, provided timber is handy.

If dummy entrenchments are constructed within the enemy's view so as to divert the fire from the true position of the guns they should be at such a distance from the latter that the effect of inaccurate and wild shots will not be felt. Under service conditions, at medium ranges, the total rectangle of a fire directed at the dummy entrenchments would be about 500 yards by 100 yards. The dummies should, therefore, be at least 100 yards from the guns.

The Russians and Boers both made frequent use of the device of a double set of entrenchments for their guns and groups of guns. When the fire of the enemy became well adjusted, the guns were simply withdrawn to the second set of entrenchments, without the rectangle of hostile fire, no change being apparent to the enemy in the point from which they received the fire of the guns they were firing upon. Hamilton, as well as the observers in South Africa, recount instances where empty entrenchments were fired upon for hours after the guns had been shifted a short distance.

There are occasions, especially in a bare, rocky country, with shallow soil, where cover is scarce and "digging in" impracticable, when it is wise for the firing battery to be well provided with empty bags. A large number of gunny-sacks may be carried on the carriages and off horses, which, when filled with loose earth or sand, will afford much protection to the pieces in action and the gun details. This means of protection will be particularly valuable against shrapnel and infantry fire, as all spaces in and about the shields of the guns may be quickly filled in with the sand bags. A number of bags could even be filled before the guns take up an exposed position, and be taken forward on the limbers.

Creeping.—It will frequently occur in action that the act of driving the guns into actual position will greatly expose the teams, by reason of the fact that the animals necessarily precede the pieces and will remain in view of the enemy, perhaps on the sky line, when the rear crest position is quite near the actual crest. In such case, not only will the teams loom up against the sky, offering an excellent target to hostile fire, but even if no loss of animals is sustained the position of the guns will be unwisely advertised among the watchful enemy, the principal advantage of the rear crest position thereby being sacrificed. To avoid this result it will frequently be best to unlimber in rear of the actual position to be taken up and post the pieces by hand, this in spite of the enormous labor and delay entailed by the accidents of the ground which will often be most adverse. This method is known as "creeping," and has elicited a volume of discussion abroad, pro and con, entirely incommensurate with its technical importance. The American soldier, characterized by ready expediency, views such a matter as more in the nature of an obvious makeshift than as one involving a mooted tactical principle. Technical treatises containing elaborate discussions of such things do much to impair the sympathy of an earnest seeker for professional information. The writer personally witnessed the

creeping method adopted upon the initiative of a chief of section at the memorable Leon Springs (Texas) maneuvers, and ventures the assertion that this particular gunner was not a student of tactics.

Visibility.—In taking up positions for direct fire the question of visibility is all-important. Every precaution possible should be taken to obscure the movements of the guns and their positions.

The keynote of a landscape is confusion of detail. All natural objects are irregular in shape and complex in outline. Any symmetrical object, such as a gun-carriage, tends to catch the eye at once. In nature there are no straight lines (except the surface of water), no circles, and no squares.

Again, there are no sharp contrasts in nature; the color and tone of all natural objects are infinitely varied. For this reason, any object of uniform color, such as the side of a house or the flat surface of a gun-shield, attracts attention immediately.

Lastly, natural objects do not move. So long as a man or a horse keeps still he escapes notice. The hunter who sits for hours waiting for a shot knows this well; he also knows that the erect figure of a man is unlike anything in nature, and carefully avoids the upright position. The stealthy Indian crouches as he creeps up to his quarry. It was a standing order in Natal that when men were seen erect on the sky line the troops were on no account to fire on them, as they could not possibly be Boers. At first erect dummies were placed along the route of the British troops, who invariably fired upon them, thus disclosing their own position to nearby sharpshooters, who worried and harassed the bravest men into a state of demoralization. Few men can unflinchingly face death at the hands of an unseen enemy. And so it was with the red-coated veterans of Braddock who melted away before an enemy whose tactics were not according to the rules of war.

The most conspicuous feature of a landscape is invariably the sky line. Not only does any movement or any artificial-

looking object thereon catch the eye at once, but the sky line forms the natural point of aim for all infantry. Accordingly, it is especially important for guns to avoid it, since artillery in action is more stationary than infantry or cavalry, and has to remain longer under fire before it can limber up and move.

Not only symmetry of form but symmetry of order or arrangement makes for visibility. A single gun might escape notice, but four guns at regular intervals, though individually barely visible, form a group unlike anything in nature, and arouse suspicion accordingly.

It takes a certain period of time for a visible but inconspicuous object to catch the eye of observers. It is therefore sound policy to reduce the period of exposure to a minimum, even at the expense of additional momentary visibility. Thus, if it be necessary to cross a ridge in view of the enemy, the best way is to form line under cover and let every carriage cross as nearly as possible simultaneously. If the opposite plan be adopted, and it be attempted to steal over in column of route, then the first carriages may possibly get over before the enemy realizes what is happening, but those following are likely to suffer severely.

In pushing forward guns in close support of infantry, it would be foolish to trot a section across the open within 1,500 yards of a position, with every gun and rifle of the defenders ready to open upon it. But when the defenders are thoroughly engaged in repelling an assault, their attention will be fully concentrated upon the attacking force nearest at hand. It takes time to perceive a more distant object, and more time to get the excited defenders to shift their fire to a quarter from which the danger seems less imminent. Therefore, a section exposed for several minutes only will have an excellent chance of getting through unscathed. But even if it do not, if the fire of the defenders is drawn to such an extent that the assaulting columns of infantry can reach the position, the artillery has fully served its purpose and has no cause to regret the

loss it may have sustained, unless the casualties could have been avoided and the same results accomplished.

We will now consider the application of the foregoing principles to service conditions.

The service uniform of the troops has been rendered as inconspicuous as possible. Most of the flashing metal work which we used to display has disappeared, and even the harness now used is of inconspicuous design and color. While the color of our material is perhaps the best, yet there is an undesirable uniformity for service conditions, though this is desirable in time of peace. In actual service the smartness in appearance of the guns and carriages should be sacrificed to invisibility, and they will probably be mottled, clouded, or chequered. The undersides of the carriages are in shadow; these parts are very dark, forming the most visible features of the equipment. This can be compensated for by giving the under surfaces a lighter tint.

Wild animals are usually of the color of their native cover. This is also true of birds, such as the quail, and of reptiles. Not only are animals tinted to suit their surroundings but they are shaded to compensate for shadows. Many of them will be found lighter along the breast and belly than on the back, making their outline practically indistinguishable at a short distance.

The flat front of a gun-shield forms a reflecting surface which no amount of paint can hide. It will be found advisable at times, in the absence of suitable brush, to break the surface by hanging gunbuckets, sacks, blankets, coiled prolonges, and miscellaneous stores upon it. Here it may be said that "bushing up" a gun by sticking brush in the wheels and hanging it upon the shield is difficult to do artistically and usually makes it more conspicuous than before. Otherwise than by its tendency to reflect, the gun-shield does not on the whole add to the visibility of the gun. We all know the distinctive appearance of a gun on a sky line, with a wheel sticking up on

each side and the muzzle in the middle. When the space between the top of the wheels is filled by the shield, it tends to obscure the character of the object, even if its conspicuousness is not reduced very greatly. Moreover, the shield hides the movement of the detachment, which movement often enables the gun to be located, or the character of the object to be determined.

The placing of a caisson immediately alongside of a gun unfortunately adds to the visibility of the position. It would be much better from the standpoint of visibility alone to post the caissons in rear of a crest. The disadvantages in other respects, however, make the prescribed position the better of the two. Not only is there great danger of its being struck in rear, but the casualties among the men supplying the ammunition while crossing over the crest are greater. In the parallel position the entire detachment is behind the shields of the two carriages.

Modern nitro-powder gives very little smoke, but the broad white flash from the muzzle is conspicuously visible, especially against a dark background, which should accordingly be avoided when practicable. It has been found that at nighttime the flare from the muzzle can be seen over a crest at a great distance when the piece is within 20 feet of the crest. Flash defilade is therefore greater at nighttime than by day. The only means of concealing the flash of the guns at direct fire is by placing them behind a screen, such as a row of thinly growing trees, that the gunners can see through. It is, however, the exception that such a natural feature is available.

It has been proposed to fix a shield to the gun, about 2 feet in front of the muzzle, with an aperture through which the projectile may pass. The impact of the gases on this shield would help check the recoil, while the visible flash would be materially reduced. The idea, as yet, has not assumed practical form.

Both when moving into position and when in action the dust thrown up often betrays the presence of the battery.

On the defensive, when there is plenty of time for preparations, it is desirable to water the ground in front of the muzzles. In a dry place, the rush of gas and air upon discharge causes a cloud of dust to rise which, added to what little smoke there is, indicates with certainty to a watchful eye the position of the guns, even though they be otherwise well screened.

In moving into position, artillery should always avoid dusty roads when sod and fields are at hand. Often, a most excellent position will be disclosed by a dust cloud when the use of a different route, even though a little longer, would have prevented the "give away." Not only will the dust cloud inform the scouts and observers of the enemy as to the exact direction of the approaching guns, but also of the probable number of the guns and the distance they are being posted behind the covering screen. If it be constantly borne in mind that a dust cloud serves exactly the same purpose with respect to a battery that the smoke-producing matrix of a shrapnel does with respect to the point of burst of the projectile, the artillery officer will require few cautions concerning the danger of dust.

In addition to dummy entrenchments, screens, etc., erected for the purpose of diverting hostile fire, dust and smoke may be created away from the true position of the guns. This was done very effectively by the Boers.

Indirect Fire.—For a field gun the angle of descent of a shell is about one-third greater than the angle of elevation. If a battery be firing at 3,600 yards, which corresponds to about 6 degrees of elevation, then the angle of descent of the projectiles will be 8 degrees. If, therefore, two batteries of similar guns are firing at each other, both being under cover so that their projectiles barely clear the covering crests, each will be able to hit the other. In other words, when engaging a hostile battery it is impossible to obtain natural cover from its fire. If Battery "A" can hit Battery "B", the latter can hit the former.

The advantage of covered positions is solely due to concealment from the enemy's view. It follows, therefore, that the cover afforded by trees, houses, hedges, etc., is just as good as that afforded by a rise of ground or an intervening hillside. A practical exception to this rule is that the cover must not be of such a nature as to act as a penetrable screen to burst the enemy's shrapnel within effective distance of the battery.

Example of Japanese Methods.—Illustrative of the Japanese methods of preparing a position before opening fire, both with a view to screening the guns and protecting the material and personnel in the event they were located, the instance of the Yalu may be cited.

The Japanese artillery were given orders to mass on Kinteito Island, about opposite the Russian center, during the night of April 29th–30th. They were to open fire at the first good opportunity given them by the Russian artillery. If the Russian guns gave them no opening they were not to fire at all. In anticipation of a duel, by daybreak on the 30th the whole of the artillery of the Second Division, together with the five batteries of twelve-centimeter howitzers, in all thirty-six field guns and twenty howitzers, had been admirably entrenched on the soft, sandy soil of the island, with the Yalu, like a huge, impassable moat, flowing along its northern face. Every advantage of the natural lie of the ground was taken, and much artifice was employed to conceal the position from the hostile gunners on the north bank of the river, 2,000 yards or more away. Trees were transplanted a short distance in front of the batteries to hide the tell-tale flash of discharge, and were carefully chosen from among those which were growing either directly in front or directly behind the intrenchment which was to be concealed. Thus next morning the landscape appeared unchanged from the Russian side of the river, as the fact that a tree of a particular shape had advanced or retired 200 or 300 yards during the night was naturally imperceptible. Poles were stuck into the sand and connected

by a string on which branches were suspended. The earth dug out of the deep gun pits was most carefully and with great labor scattered broadcast, so as not to disclose any irregularity of terrain. The howitzer pits and epaulments were connected by trenches, and numbers of covered ways leading down to the river bank were dug to insure a plentiful supply of water for laying the dust which is otherwise so apt to rise with the shock of discharge and give away a position.

When all had been done that could be done to insure concealment, then all was done that could be done in the time left to insure safety if concealment should chance to fail. Bomb-proof shelters were made for the men, and were dug so deep and so strongly roofed over with heavy baulks of timber and earth that they would have resisted heavy siege artillery, let alone the field guns, which were all they had to fear.

General Sir Ian Hamilton of the British Army declares that he could not detect these entrenchments from the other side of the river, even though he had just inspected them and knew about where they were located.*

Thus, screened from observation and protected against fire, every possible precaution had been taken toward minimizing the effect of the enemy's guns. It now only remained to perfect the arrangements for offensive action. With this object two observation stations were established at commanding points some 3,000 or 4,000 yards in rear of the batteries, from whence a good view could be obtained of the Russian camp behind Chiulienchang, and of the lateral communications, such as they were, which ran in rear of the Russian entrenchments. These observation stations were connected with the howitzer batteries by telephone, and both batteries and observation stations having duplicate maps of the enemy's position marked out in small squares, the observers on the southern heights were able, by merely telephoning down the number of a square, to switch the whole fire effect of the

*A Staff Officer's Scrap-Book, Vol. 1, p. 111.

masked batteries on to any spot where they, from their posts of vantage, could see a suitable target present itself. Platforms were also erected in trees on the flanks of the batteries, from whence officers could make local observations of the effect of their fire.

When we consider that all of this was accomplished in one night, unknown to a watchful enemy, and that so far the First Army had to fight its first engagement, all the more remarkable does it seem. The Battle of the Yalu was the opening scene of the Manchurian tragedy. How had the Japanese acquired such a mastery of practical gunnery? Not by experience, for modern field guns were as new to them as to the Russians who posted theirs so poorly; a comparison of the positions of the artillery of the two armies at the Yalu is as those of professional and amateur. The Japanese were invisible and comparatively invulnerable; the Russians were conspicuous and everywhere most vulnerable. The latter never had a chance. The overwhelming superiority of their 72 guns and 20 howitzers, not only in weight of metal but in position, was quickly overcome, and thus the Japanese were enabled to crush their opponents. In thirty minutes the Russian guns were silenced.

"Why, why did the Russian great general staff disdain to take a lesson from the Boers, who had so recently repeated for the benefit of the British, and for that of all the world as well, if it chose to take heed, the lesson of how an inferior artillery should be worked?" says General Hamilton.

The fact remains, however, that as the war progressed the two artilleries drew away from the mask, sacrificing the effect of their fire to safety of position.

Clearing the Mask.—When position for indirect fire is to be occupied it is necessary to make sure that the projectiles from each gun will clear the mask. But this is not all that is necessary, for if it were necessary to give the guns such an elevation for this purpose that the projectiles would

pass over and beyond the target the fire would be useless. The effect of the elevation on the range must always, therefore, be kept in mind.

If the mask is near at hand and the guns are in position, by sighting through the bores it may be ascertained whether the projectile will clear; but, as a rule, the position must be selected before the guns are placed, hence sighting through the

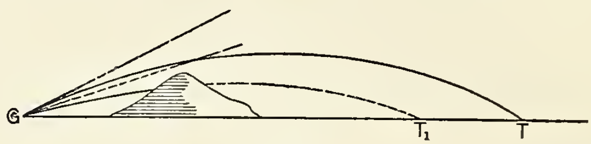


Fig. 2.

bores is impossible. Again, if the mask is distant, while the axis of the piece might clear, the trajectory for the range might not pass over the mask.

In Figure 2 the trajectory for T at range GT clears, but the trajectory for T at range GT_1 will not. For both ranges the line of fire, which is the axis of the piece prolonged, clears the mask.

Again, even if it should be found that the trajectory for a given range would clear the mask, the correction for angle of site, if one of depression, might cause the projectile to strike the mask, for, as we have seen, an angle of site for depression is in effect a shortening of the range of the trajectory with respect to the horizontal. The foregoing is illustrated in Figure 3, where the range is the same but the angles of site for T, T_1, and T_2 are different.

Now it is plain that if we can find the distance of the mask from the guns and its height, and can then determine the height of the trajectory at that point, we can tell whether the trajectory will clear.

If the crest of the mask is very distant, the distance thereto can be determined in the same manner as the distance to the aiming point, that is by the telescope and a measured base,

by the range finder, and by estimation. In the last case, it would, of course, be impractical to verify the distance by fire, when in action.

The height of the mask in mils can be determined by use of the B. C. ruler or more accurately by the B. C. telescope. Knowing the distance of the crest and its height in mils, the height in feet can easily be determined. Thus, if the crest is 1,000 yds. distant and 20 mils high, it is 60 feet high, since each mil at 1,000 yds. is 1 yd. or three feet.

We must now determine how high in feet the trajectory is

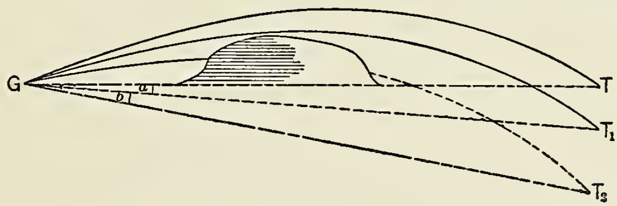


Fig. 3.

at a point 1,000 yds. from the guns. The height of the trajectory above the horizontal at any point depends, of course, upon the range and the angle of site, as we have seen in Figure 2. This height may be found by the use of the Battery Commander's Ruler. This instrument is fully described and its general use explained on pp. 114–116 of the Handbook for Three-Inch Material. It contains a white metal rule, which slides in a groove in a brass rule. The slide rule is graduated in mils from —24 through 0 to + 284. The scale of the brass rule gives hundreds of yards of range. If the angle of site is 30 mils, the number 30 on the slide rule is set opposite the division on the range scale indicating the distance to the crest of the mask.

The reading on the slide opposite the division on the brass rule, corresponding to the range of the target, gives the height in mils of the trajectory at the crest of the mask. In other words, the brass scale is for ranges in yards and the white slide gives heights in mils. Place the angle of site opposite

the range to the mask. The angle opposite the range of the target gives height of the trajectory at the mask.

Suppose we find by this method that the trajectory is 30 mils high at the mask. If the mask is 1,000 yds. distant the

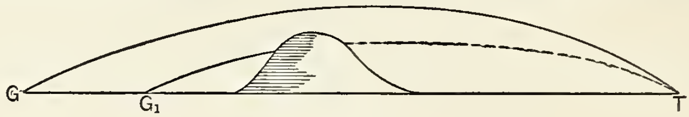


Fig. 4.

trajectory is 30 yds. or 90 feet high at that point. Now if the mask is 60 feet high the projectile will clear by 30 feet. But if the height of the trajectory is found to be 15 mils or 45 feet, and the mask is 60 feet high, the projectile will strike 15 feet below the crest. Hence, a longer range must be used, or a greater angle of site, or a combination of the two. It is not necessary, however, to add to the range in the direction of the target. The increase can be secured by moving the pieces away from the target or back from the mask, unless in so doing

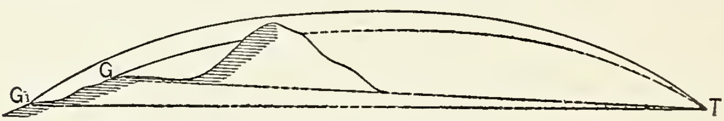


Fig. 5.

the guns would be moved up to an elevation at which they could be seen by the enemy, thus losing the cover of the mask.

When the guns are at G_1 (Figure 4), the trajectory does not clear, but upon being moved back to G (an increase of range), the increase in the height of the trajectory is sufficient to cause it to clear the mask. But suppose (Figure 5) the guns in being moved backward were moved down grade.

The tendency in such a case is to draw down the trajectory, which would have been G_1T had the guns been moved backward at the same level as G. When the guns were at G the angle of site was normal, and so it would have been at G_1.

But at G_1 it is 300+ or it has increased. Hence, as the angle of site changes when the guns are lowered, we must be careful that the increase in the height of the trajectory, gained by lengthening the range, is not counteracted by the effect of lowering the position and changing the angle of site.

It will be seen (Figure 6) that as the guns are moved to higher positions the angle of site changes from 300 to 300− and that, as it is changed by elevating the positions of the pieces, the tendency is to raise the trajectory above the mask, as G_1T and $G''T$.

If the angle of site remained constant, that is if T moved

Fig. 6.

downward as fast as the positions of the guns were elevated, only an increase of range would raise the trajectory over the mask. From the foregoing the following rules may be deduced:

1. By moving the guns backward from the mask the trajectory is heightened;

2. By moving the guns backward and downward we counteract, in a measure, this increase in elevation.

3. By moving the guns backward and upward we add to this increase in elevation.

From the following table we can plot the curve of a trajectory with serviceable accuracy. The maximum ordinate, as we know, is the perpendicular to the highest point or summit of the curve. From the B. C. ruler the exact height of the trajectory in mils at every point for any range can be ascertained by placing the normal angle of site 300 opposite the point the elevation of which is desired, and reading the angle opposite the range of the target.

A vivid impression of the rapid increase in the height of the trajectory for increased ranges is obtained when we plot these curves to scale. This interesting problem should be solved by every student of gunnery. For instance, for a range of 500 yds. the projectile rises to a point 4.3 feet above the line from gun to target, the elevation increasing to 17.3 feet for 1,000 yds., 975.0 feet for 5,000 yds., and 1,992.0 for 6,500 yds. The highest possible mask which can be used at a range of 1,000 yds. is 17.3 ft., situated a little nearer the target than to the gun because the maximum ordinate is not at the middle of the range. This is easily understood when we plot the curve and compare the angle of fall with the angle of departure. The former will be invariably found the greater of the two.

At a range of 2,000 yds. it is possible to fire over a mask 93.1 ft. high; and at a range of 4 miles one could fire over a mountain over 2,000 feet high, situated about 2 miles distant.

The height of a possible mask diminishes rapidly with its proximity to the target as well as to the guns.

Range (Yards)	Angle of Departure	Angle of Fall	Maximum Ordinate (Feet)
500	0° 31.9′	0° 35.3′	4.3
1,000	1° 11.2′	1° 27.3′	17.3
1,500	1° 59.4′	2° 38.6′	45.3
2,000	2° 56.7′	4° 07.6′	93.1
2,500	4° 01.8′	5° 48.8′	163.5
3,000	5° 12.0′	7° 41.2′	257.0
3,500	6° 28.7′	9° 43.7′	378.0
4,000	7° 54.2′	12° 02.9′	536.0
4,500	9° 28.5′	14° 37.3′	731.0
5,000	11° 10.1′	17° 26.0′	975.0
5,500	13° 10.1′	20° 29.0′	1,263.0
6,000	15° 10.8′	23° 40.0′	1,598.0
6,500	17° 12.6′	27° 06.8′	1,992.0

In calculating clearance a good margin should always be allowed for the four guns of a battery are seldom at exactly the same level, and the same holds true of the batteries of a battalion and so on. Especially important is this margin of clearance when the infantry is advancing over the intervening slopes and when the crest of the mask is near the guns. In the first case, much damage may be caused by bursts on graze among our own troops. In the second case, the explosion of shrapnel, and particularly of shell, in the immediate front of the battery is highly demoralizing, whether caused by our own

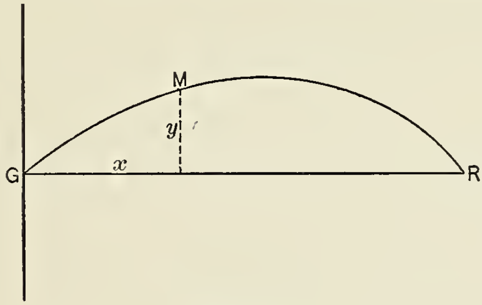


Fig. 7.

or hostile guns. In addition to the moral effect many casualties may result, and the exact position of the battery may be disclosed to the eye of the enemy.

A good rough working rule for determining the height of the trajectory may be deduced from our knowledge of its curve. Every trajectory, as we have seen in Ballistics, approximates an analytical curve, and that curve may be analyzed with respect to the horizontal and the vertical ordinates and the value of each coördinate expressed algebraically. In other words (Figure 7) the vertical ordinate y of the point M bears a definite relation to its horizontal ordinate x, the relative values of the ordinates depending upon the velocity of the projectile and the resistance of the atmosphere.

Percin's Rule.—For cases in which the height of the mask in yards is known Gen. Percin, of the French artillery, has deduced a simple rule of approximation. For the actual trajectory he has substituted a parabola passing through the origin and the point of fall, whose ordinates at all points of the range are inferior to the ordinates of the real trajectory. The equation of the Percin parabola is

$$4y = x(R—x),$$

in which

y is the ordinate in yards corresponding to any point z.
x is in the general sense any abscissa; in the special sense it is the distance from gun to mask in hundreds of yards.
R is the entire range from gun to object in hundreds of yards.

Solving for x,

$$x = \frac{4y}{(R—x)},$$

from which it is seen that, under the rule, a projectile will clear the mask when fired at a distance from the mask equal to four times the height of the mask in yards, divided by the range from mask to object in hundreds of yards.

Example: The range from mask to target is 4,000 yards; height of mask 20 yards.

$$4y = 80,$$
$$(R-x) = 40,$$
$$x = 200 \text{ yards.}$$

At 200 yards the angle of site of the mask is 100 mils; the angle of departure corresponding to range of 4,200 yards is 151.4 mils; hence it will be seen that the rule gives a large factor of safety for horizontal ranges. Even for an angle of

site of target as low as 250 the projectiles in this case would clear the mask.

Let S = angle of site of mask;

$$\text{then } S = \frac{\frac{y}{x}}{10} = 10\frac{y}{x},$$

$$\frac{y}{x} = \frac{S.}{10}$$

From the equation of the parabola above

$$\frac{y}{x} = \tfrac{1}{4}\,(R—x),$$

or

$$\frac{S}{10} = \tfrac{1}{4}\,(R—x),$$

or

$$S = 2.5\,(R—x).$$

From which it is seen that the trajectory will clear if the guns are placed at a distance from the mask such that the angle of site of the mask from the gun, in mils, is equal to or less than two and one-half times the distance from mask to target in hundreds of yards.

MILES' METHOD.—It is not always practicable to employ the B. C. ruler or Percin's rule in solving the problem of clearing the mask. Lieut. Miles of the United States Army offers an interesting solution.

Suppose for instance the mask is a gently sloping crest within 100 yards of the guns. To use the sliding scale we must know the distance from the guns to the top of this crest. It is often difficult to locate this exact point; but even if we do locate it, and apply the sliding scale method, nothing more is determined than that the guns will or will not clear that particular point. If they do clear it there may be another slightly lower point nearer the guns which may touch or be above the

curve of trajectory. To the solution of the problem in this case, then, the sliding scale method is not in practice applicable.

The following method is particularly applicable to this common case of the guns being on the reverse slope of a slightly convex hill. The two factors considered are—

(a) The angle of departure of the projectile.
(b) The angular height of the mask above the guns.

In order that the projectile may clear the mask (a) must be greater than (b).

If, as in the first form of the problem, we wish to find the minimum range, (b) is first measured. The value of (a) is then established, since it must be slightly greater than (b). And, since (a) is equal to the algebraic sum of the angle of site and the elevation of the gun due to range, the elevation due to range is determined for any given angle of site. By reference to a table showing the elevations for all ranges the minimum range is obtained.

If, as in the second form of the problem, the target is known, and we wish to find a position from which the mask can be cleared, one or more positions are tried. The practicability of clearing from any trial position is determined by measuring (b) and finding (a) by adding the angle of site of the target and the elevation corresponding to the range to the target. This elevation is taken from the table spoken of above. The angles (a) and (b) having been determined, the guns will clear the mask from that trial position if (a) is greater than (b), otherwise not.

Now, as to the method of measuring these various angles, and the form in which they should appear. It is easy to construct a table showing for all ranges the angle *in mils* of elevation of the gun due to range (with normal angle of site). The value of an angle in mils, divided by 1000, is approximately the tangent of the angle. This approximation is sufficiently close, especially for the smaller angles. For example, the tan-

gent of an angle of 200 mils (11 degrees, 15 minutes) is 199/1000. No greater error is made if we take 200/1000. The angle of site could similarly be easily put in tangent form by dividing the mils by 1000. The angle (b), being an angle of slope, could easily be measured in tangent form, as, for example, a slope of 1 on 20 from the guns to the top of the mask. Thus the three angles involved are readily put in the form of tangents, with a common denominator of 1000. If the reconnaissance officer carried a clinometer graduated in mils the problem would be simplified, and he would, moreover, be able to read angles of site far more readily and accurately than by any instrument at present issued.

How would this method of determining the practicability of a mask work out in the field? Let us imagine the typical case of an officer sent out to find a defiladed position to fire on a given target. He finds several positions, each more or less fulfilling the requirements of defilade, good range, accessibility, etc. He decides to examine them in detail, beginning with the one that seems the most promising. This position offers a flash defilade on the reverse slope of a slightly convex crest. He wishes to determine whether or not the guns can clear the crest. He carries a clinometer graduated in mils, and, on the case of the clinometer, a table showing the elevations in mils due to range. He first goes to the top of the crest and there verifies his first estimate of the range (he would have to do this in any case). Looking at his table he finds the angle 130 mils opposite his determined range of 4000 yards. With his clinometer he measures the angle of site to the target—minus 5 mils. He corrects this for the position of the guns 4 yards below and about 30 yards to the rear—say minus 4 mils. Going to the proposed position of the guns he holds his clinometer at the height of a gun above the ground and measures the angle to the top of the crest—120 mils. Then—

130/1000 — 4/1000 = 126/1000, and is greater than 120/1000. He sees that the guns would just clear the crest—

for safety they had better be moved a little nearer. He also is able to give the battery or battalion commander the correct range and angle of site.

It will be observed that unless the angle of site of the target is greatly above or below the normal the officer will make no appreciable mistake if he does not stop to correct the angle of site measured from the top of the crest.

Dead Space.—It must not be thought that the sole consideration in taking up a covered position is whether or not the projectile will clear the mask. The flat trajectory of a modern field gun imposes certain limitations on it, which must be borne in mind when selecting a covered position. The angle of elevation of the 3″ gun is only about 3° for 2,000 yards and 5° for 3,000 yards. Therefore, if the covered position be such as to require 3 degrees of elevation to clear the mask, the whole of the foreground within 2,000 yards of the guns will be dead space. On the defensive, then, the minimum of cover necessary to screen the guns from hostile view will have to suffice, since the guns exist to repel the enemy and not primarily to be hidden by cover.

The sector of fire assigned the guns, and the character of the included terrain, will generally determine whether a position on the rear crest of the mask or one well back therefrom will be taken up. If the position of the enemy is near the forward face of the mask the position of the attacking guns will necessarily be well away from the mask. But if the position to be attacked is well in advance of the mask it can be reached by the fire of guns either just in rear of the mask or well back therefrom. The former is generally the better position since the range is shorter, the fire therefore more effective, and since the guns can be run up to the "rear crest" position if direct fire becomes necessary. Again, all short shots are ineffective as well as the "overs," whereas if the second position is taken the "shorts" may have a demoralizing effect since the majority of them will be visible.

The principal disadvantage of the more advanced position is that the enemy will be more apt to search the reverse slope of a likely mask than the terrain well back therefrom of which they can see no part, and without making a reconnaissance know nothing of, unless a detailed map of the country is at hand.

Danger Angle.—When the rear position is taken the crest of the mask must be kept clear for a distance equal to the

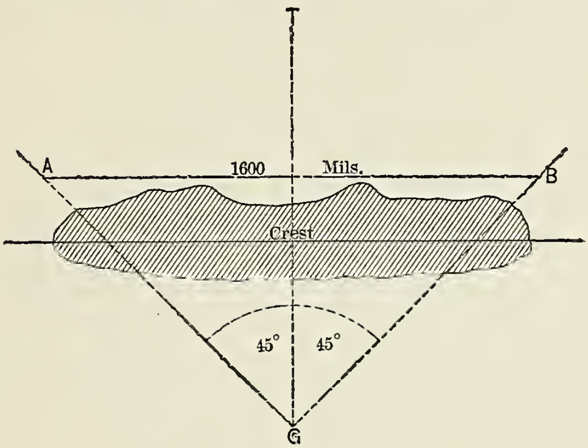


FIG. 8.

front of the battery, plus a distance on either side equal to that of the battery from the crest. This is necessary in order not to infringe on the "danger" angle of 45° from the muzzles of the flank guns with the true direction of fire; that is, if the battery is 100 yards in rear of the crest, it will require the crest to be kept clear of other troops and other guns for 300 yards; if 200 yards in rear, 500 yards of crest must be unoccupied by friendly troops. Hence, the battery commander cannot use the logical position from which to make his observations without moving far to the flank; the best station being, of course, on the nearest crest from which the enemy is visible beyond the mask.

The entire danger angle is 90° or 1,600 mils of crest. It is found in practice that wild shots will frequently burst in this sector. The width of the sector is determined by errors in laying, and its depth by premature bursts due to error of fuze. In other words, a man standing anywhere in the angle AGB (Figure 8) is apt to be killed by the fire from his own guns at G, although the target is at T.

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